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OF THE

ROYAL AERONAUTICAL SOCIETY

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Edited for the Council by J. LAURENCE PRITCHARD, Honorary Fellow

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NOTICES

Election of Members

The following Members were elected at a meeting of the Council held on October 16th:—

Associate Fellows.—Mr. S. H. Evans, Mr. A. P. Rowe.

Students.—Mr. G. A. Chamberlain, Mr. L. G. Brazier, Mr. S. W. Slaughter, Mr. F. Small.

Temporary Honorary Member.—Lieutenant S. Kato, I.J.N.

Foreign Member.—Mr. S. A. U. Rasmussen.

SCOTTISH BRANCH.—*Member.*—Captain A. N. Kingwill.

Honorary Librarian

Mr. J. E. Hodgson, Associate Member, has kindly agreed to act as Honorary Librarian. Mr. Hodgson has recently undertaken the re-arrangement of the Library, which has resulted in the valuable additions purchased with the grant from the Carnegie United Kingdom Trustees being now adequately displayed. It is hoped shortly to publish a complete hand list of the books, pamphlets and periodicals.

Associate Fellowship Examination

The following is the list of successful candidates in the Society's examination which took place on September 25th: Mr. P. A. Ralli, Mr. P. H. Watson and Mr. M. W. Wood.

Scottish Branch

The complete programme of lectures arranged for the Session by the Scottish Branch is as follows:—

1923.

Oct. 11th, 8.0 p.m. Major-General Sir F. H. Sykes, "Some Aspects of Aeronautical Progress." *Chairman*—Lord Invernairn.

Nov. 13th, 8.0 p.m. Mr. F. T. Courtney, "The Practical Difficulties of Commercial Flying." *Chairman*—Brig.-Gen. J. G. Weir.

Dec. 10th, 8.0 p.m. Professor Gordon Gray, "A Complete Solution of the Cloud and Night Flying Problem."

XUM

1924.

Jan. 29th, 8.0 p.m. Mr. A. H. R. Fedden, "Radial Air-Cooled Aero Engines." *Chairman*—Mr. Harold E. Yarrow.

Feb. 12th, 8.0 p.m. Mr. A. E. L. Chorlton, "The Beardmore 1,000 h.p. Engine." *Chairman*—Professor Hudson Beare.

March 11th, 8.0 p.m. Captain W. H. Sayers, "Gliders." *Chairman*—Sir John Reid.

April 4th, 8.0 p.m. Col. the Master of Sempill, "The British Aviation Mission to the Imperial Japanese Navy." *Chairman*—Professor Cormack.

April 10th, 8.0 p.m. Mr. F. Handley Page (subject to be announced later). *Chairman*—The Right Hon. Lord Weir of Eastwood.

Cambridge University Aeronautical Society

The following programme for the first half of the Session has been received from the Secretary (Mr. Basil B. Henderson, Gonville and Caius College):—

1923.

Oct. 17th, 8.30 p.m. Mr. F. Handley Page, "Commercial Aviation."

,, 24th, 8.30 p.m. Mr. E. C. Gordon England, "Gliders of the Past and Present."

,, 31st, 8.30 p.m. Mr. J. D. North, "Science and Art in Aviation."

Nov. 7th, 8.30 p.m. Admiral Mark Kerr, "The Air and the Empire in Peace and War."

,, 14th, 8.30 p.m. Sq.-Ldr. G. S. Trewin, "Aircraft Co-operation with the Fleet."

,, 21st, 8.30 p.m. Maj.-Gen. Sir W. Sefton Brancker, "Air Transport."

,, 28th, 8.30 p.m. Captain W. H. Sayers, "The Theory of Flight."

Dec. 5th, 8.30 p.m. Major H. E. Wimperis, "Some Aeronautical Problems."

Other Societies

The following list of lectures on aeronautical subjects before other Societies and Institutions is published for the information of Members. Tickets for any of these lectures may be obtained through the Secretary:—

1923.

Dec. 14th, 6.0 p.m. *Institution of Mechanical Engineers.*—Prof. A. H. Gibson and Mr. A. Wright Baker, "Exhaust Valve and Cylinder Head Temperatures in High-Speed Petrol Engines."

1924.

Jan. 9th, 6.30 p.m. *Institution of Automobile Engineers.*—Mr. A. J. Rowledge, "Water-Cooled Aero Engines."

March 3rd, 5.30 p.m. *Institute of Transport.*—Mr. G. Holt Thomas, "Air Transport and Its Uses."

Date to be announced. *Institution of Mechanical Engineers.*—Dr. H. Moss, "Air Consumption and B.H.P. of Aero Engines."

Donations

The Council desire gratefully to acknowledge gifts of lantern slides from the following firms:—

The Bristol Aeroplane Company, Limited,
The de Havilland Aircraft Company, Limited,
The Fairey Aviation Company, Limited,
Short Brothers (Rochester and Bedford), Limited,

and of photographs from the Blackburn Aeroplane and Motor Company, Limited.

Forthcoming Arrangements

Thursday, Nov. 1st, 5.30 p.m.	Major H. E. Wimperis, "Some Recent Developments in Aircraft Instruments."
Tuesday, Nov. 13th, 5.30 p.m.	Council Meeting.
Thursday, Nov. 15th, 5.30 p.m.	Mr. H. R. Ricardo, "The Thermodynamics of Aircraft Engines."

The lectures take place at the Royal Society of Arts, 18, John Street, Adelphi, W.C.

W. Lockwood Marsh, *Secretary.*

R38 MEMORIAL PRIZE, 1924

Regulations

From the income of the above fund a sum of twenty-five guineas will be offered as a prize for the best paper received by the Royal Aeronautical Society on some subject of a technical nature in the science of aeronautics. Other things being equal, preference will be given to papers which relate to airships.

The prize is open to international competition. The Royal Aeronautical Society retains the right to withhold the prize in any year if it is considered that no paper is of sufficient merit to justify an award.

Intending competitors should send their names to the Secretary of the Royal Aeronautical Society, 7, Albemarle Street, London, W.1, on or before December 31st, 1923, with such information in regard to the projected scope of their papers as will enable arrangements to be made for their examination. The closing date for the receipt of papers will be March 31st, 1924.

Papers, which must be submitted in either French or English, should in all cases be typed, and a copy should be retained by the author as the Society can take no responsibility for the loss of copies submitted to it.

Successful papers will become the absolute property of the Society and will in most instances be published in the Journal of the Royal Aeronautical Society. A signed undertaking must accompany each paper to the effect that publication has not already taken place and that the author will not communicate it elsewhere until the Society's award is published.

The Society attaches special importance to papers showing original work, and due acknowledgment must be made by the author of the source of any special information.

PROCEEDINGS

Inaugural Meeting, Fifty-Ninth Session

The first meeting of the 1923-24 Session was held in the rooms of the Royal Society of Arts, John Street, Adelphi, London, on Thursday, October 4th, 1923, when the Chairman (Colonel A Ogilvie) delivered his Inaugural Lecture, entitled, "Gliders and Light Planes." The chair was occupied on this occasion by Professor L. Bairstow, retiring Chairman.

Presentation of Pilcher Memorial Prize

The Chairman said that the first business of the evening was the presentation of the Pilcher Memorial Prize, which had been awarded to Mr. A. P. Rowe for his paper on "Air Navigation." On behalf of the Society, therefore, he asked Mr. Rowe to accept the prize, which consisted of books.

Mr. A. P. Rowe received the prize amid loud applause.

The Chairman, proceeding with the ordinary business of the meeting, said that in accordance with the scheme introduced last year for the first time, one of the penalties of becoming chairman of the Society was that the holder of that office must read the first paper of the session and spend such time as was necessary to prepare it. He believed that during the last few weeks Colonel Ogilvie had found it difficult to find time to prepare his paper. The competition for the prizes offered by the Duke of Sutherland and the "Daily Mail" for gliders and light planes was to be held during the coming week and Colonel Ogilvie had a great deal of work to do in connection with this.

Colonel Ogilvie then read his paper.

GLIDERS AND LIGHT PLANES

BY COLONEL A. OGILVIE, C.B.E., M.I.MECH.E., F.R.AE.S.

Before starting on my paper to-night I should like to express two things which are much in my mind, gratification at being elected chairman of this long established scientific society and nervousness at the prospect of stepping into the shoes of Leonard Bairstow.

Professor Bairstow is one of the most important assets which this country possesses and he has been of great service to the Society for many years and particularly for the last year as chairman.

Although few, if any, of us present are able to reach his high level of scientific attainment, we are all able to appreciate his courage when carrying through arduous research work as well as his modesty when it is done.

On the Council of the Society as well as in many other connections I have worked with Professor Bairstow for many years, and I am sure that I am only voicing the views of members when I say that he has been one of the very best chairmen we have ever had, conscientious, patient under difficulties, and always steadily pressing towards the high ideals he has set up for the Society and himself.

Regarding the paper which I am supposed to be reading to you to-night as my inaugural address as chairman, I must ask for your indulgence for its inadequacy; the preparation of it has been so much interfered with by the recent

international seaplane race and by the forthcoming competitions at Lympne that I have not done proper justice to the subject, interesting though it is to me. My best excuse is that I am affording you an opportunity for a discussion on gliders and light planes which we have not had as yet in the Society and which should be of value.

My first thought on this subject is that we are opening up another path, which may lead us to a really successful application of aeronautics to peace purposes. Success in peaceful commercial work is now, even in the highest circles, becoming recognised as a necessity for success in times of trouble.

In my paper to the Air Conference in February on gliders, I attempted to draw attention not only to the great benefit which aeronautics had sustained in the past from experiments with gliders, but to the benefits obtainable in the present and in the future.

Gliders and light aeroplanes afford the best possible means of full-scale research, from which data can be gathered and ideas stimulated, towards the development of the commercial aircraft of the future. Make no mistake, it is to commercial aircraft, not to war aircraft, we must look for our real future in the air and for that we must make commercial aircraft to be real paying propositions. Can this be done? My answer is no; at the present state of knowledge the best designer in the world cannot make an aeroplane which is a real paying proposition in the commercial sense. I say this in a room full of designers for whom I have the utmost admiration and respect and from whom I never got "No" for an answer to any problem set in the war time. Then it was different, for when a designer found he could not give the necessary performance with the engine proposed, he looked around till he found one big enough to do the job. Now, unfortunately, that will not do as we, and not an indefinite State department, have to pay for the petrol and for the depreciation and insurance of our expensive machines and simply that system cannot be adopted. The experience of the last few years has shown that clearly enough to those who seek the truth.

With your permission I will read the following paragraph from the Conference paper:—

"Civil aircraft are not sufficiently safe in the event of a breakdown of the motive power, necessitating a forced landing. Undoubtedly some types are safer than others, but in all types the demands on the pilot are too severe and the risk of an accident too great.

"Civil aircraft are also much too expensive to buy, to run and maintain in running order, and until very considerable improvements can be effected in this respect, it cannot be claimed that they are transport vehicles of a really commercial character.

"The size of commercial aircraft is so great that the cost of building such machines for experimental purposes is practically impossible to private firms, apart from the cost of the large quantities of fuel required, of the maintenance parties and of the large shed accommodation and other overheads.

"State support and control of the experimental work necessarily means a measure of control of that work and it is not and cannot be really satisfactory because the man who has initiated and is conducting the experiments must be free to follow out his own ideas."

The position is therefore that those manufacturing firms who are willing and anxious to do the experimental work which will enable them to design and make better aircraft cannot afford to do so because of the small number of orders they can expect and because of the prohibitive cost of full-scale experimenting with aeroplanes.

Certainly the transport firms, notwithstanding their urgent need for improved machines for their services, cannot afford to experiment with unknown types.

It is of the utmost importance to them to simplify their organisation as much as possible. So we have to fall back on the Air Ministry, whose method is to get out a specification just beyond the attainment of designers and ask for tenders. Sometimes a firm puts up so strong a case that it gets an order for a machine incorporating some of its own ideas.

Neither system is satisfactory as regards results, owing to the delays and restrictions inevitable with Government departments, even the best of them. It is only the very exceptional designer who can supply the transport firms with anything which they can use at all.

It is hoped that the difficulties of this situation will be relieved by the glider and light plane, which enable firms to experiment at a comparatively low cost. It strikes me as a very significant thing that there should be so keen an interest in the forthcoming competitions. The actual prizes so wisely and generously put up have formed an immense attraction to pilots and designers in Belgium and France as well as all over this country, and we look like having a remarkable gathering of new designs. Would anyone a year ago have believed that a competition could take place for which nearly thirty new types of aeroplanes would be designed and built? Does anyone now doubt that valuable data and ideas will not result from such an effort? It is baiting with a minnow and catching a whale. Usually in official competitions it is the other way about. It is interesting to note that all the machines have been built as in pre-war days without departmental restrictions.

What results may we look for from the light plane? Personally, I am sceptical about the immediate appearance of large numbers of small sporting machines for one or possibly two people to cruise about the countryside. Up to date the control problem is not sufficiently solved for an aeroplane to be suitable for the general public to use for their own private touring from place to place. The performance of a new machine is usually as anticipated, but there is not a designer living who can guarantee that his new type of machine will behave in a perfectly normal manner under all circumstances, and even if he could the normal control is not good enough. The very fact that test pilots are employed proves this, unless the possibility is admitted that all test pilots are banded together in a secret society to bamboozle designers—a possibility which I personally should hesitate to accept. Until the problem of aeroplane control, particularly at low speeds, has reached a more satisfactory solution, there would be so serious a crop of accidents that people would become alarmed and aeronautics would take a set back instead of a step forward.

As far as can be judged we are not likely to get any very startling advance on control questions. In fact it is possible that we may be rather disappointed in this respect. Whether that will be so or not I am convinced that the time is not yet ripe for a widespread issue of small sporting aeroplanes among the general public.

It is a risky business to prophesy, particularly so near to the event, but in my opinion the most valuable result from these trials, apart from the further arousing of public interest and the beneficial effect of such an encounter of designers, will be the demonstration of higher aerodynamic efficiencies than we have known up to date—in other words, of better gliding angles.

What is the best gliding angle of a modern aeroplane? I mean by this the slope up which the engine has to pull the aeroplane in level flight, not the slope down which the aeroplane slides with stopped engine to make a landing.

I noticed in some recent publication that Professor Bairstow puts this angle at 1 in 9. I should have thought that figure a little optimistic and that 1 in 8 is more correct for our present commercial aeroplanes. It is certain that some of these small machines are doing better than 1 in 10. Although I myself have never seen any proof that 1 in 12 has been accomplished, I feel confident that

figure will soon be reached. I once heard Major Gnosspelius make a remark which has been in mind ever since, "A train will run down a slope 1 in 50, why not an aeroplane?"

Putting figures like that on one side—suppose one of the machines is demonstrated to have an angle of 1 in 16, what results from that? We should then know that comparing that particular machine with our present commercial ones, only half as big an engine would be required for the same work, meaning half the fuel bill, half the initial cost of the engine, half the insurance and depreciation costs of the engine and probably much less maintenance cost.

Some of a pedantic turn of mind might argue that the general arrangement of a commercial machine is so widely different from that of the light plane, that the design of the former does not benefit from improvements of the latter.

To that I would answer that a demonstration of what can be done is always of great value in stimulating thought and ideas and in setting up a standard to work towards.

From such information as I have been able to collect about these small aeroplanes, one or two interesting points appear. The first is that there is evidently no uniformity of opinion amongst designers as to the right general type to adopt, monoplane or biplane. One would certainly think that in a case like this the monoplane is the most efficient, but if the span becomes too great that structural considerations would affect the application of the full aerodynamic gain to large machines. From that point of view what we really want is an efficient monoplane of low aspect ratio.

Another point is in connection with the climb. There seems to be a singular reluctance on the part of some of these little machines to climb the first 100 feet, and no one seems to understand why. The only serious attempt at an explanation which anyone has given me was that this defect was caused by the super-efficiency of the machine. Certainly the defect if translated to the large machine would be a very serious one indeed. At present the limiting factor in practical transport technique is the ability to get off the ground and climb the first few hundred feet. The greatest efforts are applied to improve commercial aircraft in this respect. Personally, I find this point of poor initial climb very interesting because it appears to be the point where these modern machines are different from the old Wright machines, with which I am very familiar and which in some respects of loading per square foot and per horse-power were quite comparable. I have seen Wilbur Wright flying at over 55lbs. per horse-power and he had no difficulty in climbing steadily as soon as he got off the ground. My own first machine was loaded about 2½lbs. per square foot and about 40lbs. per horse-power. Its top speed was about 40 m.p.h. and I remember flying a circuit at Lanark at less than 25 m.p.h. There were two propellers of 8ft. 6in. diameter turning at about 400 revolutions and I suspect that it is in the propellers that the main difference of climb is to be found.

I hope that some experiments will be directed to the development of geared-down propeller systems.

These machines to be useful should be able to climb at a steep angle, in other words, at a slow forward speed.

On the other hand engines are steadily increasing their revolutions in all forms of locomotion—look at the geared-down turbine as well as the modern car. This process of increasing the revolutions is sure to go on, and I expect to see internal combustion engines at 10,000 revolutions per minute within a few years.

I am unable to see a direct drive propeller at 10,000 operating efficiently on an aeroplane climbing at a low forward speed of say 30 miles per hour.

It appears to me that it should be possible to develop a propeller system which would enable the full power of the engine to be effectively used from the time it is opened up, which would give a very steep angle of climb, which would be efficient at top speed and which would at the same time act as an air brake when gliding down without engine. A fine angle of descent is an advantage if the engine stops in the middle of the Channel to help you across to one side or the other, but is a serious disadvantage when actually landing, even on an aerodrome.

Members who have seen Hamel land will remember how he used to stand his Bleriot on its head and stop exactly where he wished in the smallest field.

This was chiefly because the gliding angle of the Bleriot was about 1 in 4 and the machine could be forced down at a steep angle without gaining too much speed.

Discussion

Mr. W. O. Manning said that he thought they were all indebted to Colonel Ogilvie for again drawing attention to the early work of the Wright brothers. The past machines made by them, although larger and more powerful than the modern light aeroplane, flew quite well with a horse-power loading of between 40 and 50lbs. per horse-power, a figure which has only been again approached quite recently.

During the war the improved performance of aircraft was obtained almost entirely by the progress in engine design; in fact, it is probable that no war machine at the present day has a better gliding angle than the old B.E.2, and although more is known about controls, it is not unfair to say that the improvement in aerodynamical efficiency has been nil.

Those of us who have been experimenting with light aircraft have felt that with the increased amount of information and experience that is available now it should be possible to produce types which are materially more efficient than the older forms, and the present light aircraft give some idea of what is possible in this direction.

It is not possible at present to construct commercial machines to similar models as structural considerations impose limitations, but there is no doubt that lessons will be learnt from these small machines which can be used to improve larger ones.

Colonel Ogilvie's list of structure weights for light aircraft shows that these weights are distinctly in proportion higher than those of larger machines, but it is possibly fairer to compare the weight empty and weight loaded. As the percentage engine weight is very low this ratio compares favourably with that usual in large aircraft.

With reference to the difficulty experienced by certain machines in climbing near to the ground, three explanations appear possible—that the wind conditions on the aerodrome low down are such that there is a gradient equal to the climbing angle of the machine; that the machine may be side-slipping slightly and that the design is such as to increase resistance abnormally when side-slipping; and that the machine may have two types of air flow, either of which may be to some extent stable. Of these explanations I prefer the first and it would be interesting to learn if this trouble occurs in all wind directions on the particular aerodrome used and whether or not it is peculiar to this aerodrome.

Major Gnosspelius, who designed the "Gull" light aeroplane, said that there was one remark made by Colonel Ogilvie which had appealed to him, and that was that aircraft at the present time did not pay, from a civil point of view. They were quite hopeless; and really, if we wanted to do anything we had to

make them pay somehow or other or else they were bound to die. No business could subsist on a subsidy for very long. It seemed to him that there was only one way of making them pay, and that was by decreasing the power necessary for flight; the small machine might help by enabling the experimental work to be done at reasonable expense, although the expense really was far from light. People talked of £100 and £200 for a machine, but he thought Mr. Manning would agree that £500 was about the lowest figure at which small machines could be turned out, at any rate in small numbers; perhaps the cost could be lowered if they were turned out in larger numbers. But there was another factor which entered into the problem, namely, that it did not much matter what we made, there seemed no market at present. Of course, one fact which helped very much in connection with these small machines was that there were no Government restrictions so far; that was a distinct help, because when we had to get designs passed the process always took an infinity of time and we never got ahead. Another point that Colonel Ogilvie had brought out was the question of engine power. Frankly, he did not know what the power of these small engines was. He had been told what the makers said it was, but possibly that was not what the engines gave. One of the things that should be done was to try to test these engines in order to find out what their actual power was and at what revolutions they developed this power, because the power actually obtained from different engines seemed to vary a great deal. Again, no two men obtained anything like the same power from their engines. It was a curious thing that the makers of motor bicycle engines told users to run them as fast as they could and to get as many revolutions out of them as possible, but not to open the throttle wide. He supposed that the compression ratio was so extraordinarily high that if a motor bicycle engine were run with the throttle wide open for any long period the plugs would get too hot. If we could only get data as to the actual power of these engines it would help a great deal in judging the performance of the machines, because otherwise we could not really say whether the machines were an improvement on that which already exists. He believed that the Blackburn 700 c.c. engine gave something like 24 h.p., and the Douglas gave about 26 h.p. at maximum h.p. With regard to controls, he did not know that they were so very difficult; he had not been troubled with them. The question of control had nothing to do with physical dimensions; slow speed, perhaps, did affect it slightly, but even then he personally was inclined to think that control would be easy where thin wings were used rather than where thick wings were used.

Captain G. T. R. Hill said what he wished to press for when small machines came into more general use—as he hoped they would—and what would be an absolutely essential feature if they were to come into more general use, was that they should have a sufficiency of power or, more strictly, a sufficiency of surplus power in order that the engines should not be required to run near their maximum revolutions throughout a flight. At the present time there was talk of the Government waiving its many regulations and restrictions as to flying aeroplanes, provided the power of the engine was below a certain figure. He did not think that that was really wise, and in illustration of his point he made use of an analogy. A few years ago, he said, cattle were slaughtered by means of the pole-axe, but more recently the humane killer had been introduced, which destroyed the animal by exploding a cartridge. No doubt this destruction of cattle was carried out under the supervision of the Ministries of Health, Munitions, and so on (laughter), and it seemed to him that the waiving of the restrictions on the light aeroplane below a certain limit of power would correspond with the waiving of restrictions on slaughtering cattle on condition that the cartridge used should not exceed a certain size. Surely it was at this point that restrictions should be most severe, because if the cartridge were not quite powerful enough it might only partly kill the animal; in the same way, if designers of small aeroplanes were working to a

definite engine power limit, beyond which they were not allowed to go, the probability of trouble would be obvious. Naturally they would want to build machines as large as possible up to the engine power limit, and that would lead to the restriction of reserve power. The chief advantage of the limit of engine power lay in the fact that it could be easily comprehended by both the officials of the Air Ministry and by our designers. A better kind of limit would be to rule that any aeroplane must be able to fly on, say, half its maximum power.

With regard to control, it had been suggested that thick wings allowed less lateral control. It would be interesting to find out whether that was really so or not. He was not a thick wing enthusiast, as some people in Germany were, but it remained the fact that the Fokker D.7 biplane, which was used so much by the Germans during the war, had a thick wing and was extraordinarily good on the controls. There was that definite evidence that a thick wing section need not necessarily lead to trouble with the control.

The point raised with regard to failure to climb well soon after leaving the ground was very interesting. He felt quite unable to explain it, but it was no good denying that it did occur, and it was well worth seeking for the reason. Of course, down currents on a slow-climbing aeroplane would obviously make an appreciable and visible difference, but there seemed to be something more than that. As regards loss of power due to side-slipping, he did not know of any data which might support that. He was rather of the opinion that when side-slipping anything up to about 5 deg. on the bubble, there would be no appreciable loss in gliding angle. He did not know whether anybody could support the contrary theory with figures, but he hoped they would if they could.

Finally, he asked whether the Society, remembering it was up against the "Daily Mail," would do its best to abolish the abominable term "motor glider."

Major A. R. Low, dealing with structural weight, said he had a theory—which was supported by many people, including Professor Bairstow, but opposed by others—that as the dimensions of a machine increased the famous law of the cubes came and sat on the structural weights and made them rise so rapidly that presently a limit was reached beyond which an aeroplane could not be constructed. That theory, quite definitely, was not based on the best practice he could find recorded, that at about five or six tons we were getting everything we could out of the materials, at 10 tons we were not getting the full return, and at about 15 tons we ran into a dangerous load where the factors of safety and controllability could not be kept up adequately. At the other end of the story came the small machine and the model and a very interesting point arose. It was claimed by the advocates of large machines that they could fine a number of details, and he believed that was quite true up to about five tons. Beyond five tons, however, the amount of fining that was going to be obtained could be expressed as a very modest percentage, but with the very small machine it was the other way. To take the case of the "Wren," he understood from Mr. Manning that his minimum factor of safety was four or five, but in lots of places it was 30 or 40, because the members could not be fined down without including a spar or something which would break if one laid one's hand on it. He had plotted a curve, ranging from the 12-tonners of the American Navy at one end to the "Wren" at the other. If one could build a small machine as finely as one could build a large machine, then structural weights would be the same for both machines. As an example, he said that if we could build a bridge with a span of 10 or 20ft., with a piece of lace-work such as that of the Forth Bridge, with its 1,700ft. span, then the curve of structural weights should be a horizontal straight line. But with his curve the result came out that the ratio of structural weight of a small machine to the structural weight of a really large machine was something like 12 to 4. It was really three times as heavy in its wing as the large Handley Page or Farman Goliath, and that was quite unavoidable, because

we could not make a practicable aeroplane with a lattice-work of structural members such as those of the Forth Bridge. With regard to gliding angle, 1 in 9 was considered by the lecturer to be too high and 1 in 8 to be more probable, but he did not think that squared with the results obtained from the "Wren" in actual flying.

Colonel OGILVIE pointed out that his figure of 1 in 8 referred to the commercial machine of to-day and had nothing to do with the glider.

Major LOW replied that as the lecturer had saved his position he would attack the Chairman, who had published, he believed, a figure of 1 in 9 as a suitable estimate of what the motor glider could do. That did not quite square with the known performance of the "Wren." He considered that it ought to be placed very much higher and invited Mr. Manning to give some sort of estimate based on his tests. He should think that it should be considerably above 10. As to controllability, this, he believed, was largely a psychological problem. At one time he had had to collaborate in carrying out climbing tests on all sorts of machines at Brayle station. Some were well-known standard machines and others were fearful and wonderful freak machines of novel design. With a standard machine they obtained a nice straight climb, but the creep machines always went up on a beautiful curve. He believed that that was largely a psychological effect and was possibly due to the pilot being nervous near the ground, but when he got to 2,000 or 3,000ft. he pulled the machine back to its climbing speed and climbed faster. On a number of the standard machines there was always a tendency, especially on gusty days, for the climb at lower levels to be slower relative to that at higher levels. There seemed to be a loss of energy; there was no reserve power and a gust of wind might make the machine lose quite an appreciable amount of climb by forcing it momentarily over the fast climbing angle into a stalling position, owing to side-slip. With regard to the propeller, the smaller the diameter the higher the speed it will attain. If the diameter were reduced from 9ft. to 3ft. the revolutions would increase from 1,000 to 3,000 without loss of efficiency.

In reply to Mr. Handley Page's remarks on the possibility of larger machines, I should like to know whether he is speaking as a designer of genius or as a salesman of genius.

Mr. F. HANDLEY PAGE said that the figures which Major Low had given for the structural weight of large size machines, or the conclusions he had drawn from them, were hardly correct. Speaking of the 30,000lbs. Handley Page machine, the factor of safety for that was four and the structural weight was, he believed, 31 per cent., so that, although the machine weighed about 15 tons, this machine had not the ascending part of the structure weight curve of which he (Major Low) was speaking.

With regard to motor gliders, one of the things that instantly occurred to most people, particularly those associated with the Press, was that the motor glider heralded the dawn of a new era in commercial aeronautics. It was said that we were going to have machines which, carrying 100lbs. per horse-power, would attain a speed of about 100 miles per hour, but the actual figures showed that, although the machines were more efficient in the weight per horse-power which was carried, the speeds reached were not anything like sufficient for commercial work. Machines such as the "Wren," with a top speed of 50 miles per hour, were extraordinarily efficient machines, but their speed would have to be increased to two or two and a quarter times the top speed to enable them to be of any use for a service between two points in all kinds of weather. But when we sought to attain greater speed we began to increase the horse-power and the weight, and to add all sorts of things, and eventually arrived at a commercial aeroplane not very much different from the machine which Major Gnosspelius had described as perfectly hopeless.

In that connection it must be borne in mind that the cost of upkeep and operation of the aeroplane, on the technical side, was not the only cost involved in running an air service. During the months of November, December and January there might be a week in which there was fog over the whole of the country in which they were operating, and during which there was no possibility of flying at all. If the people on the ground who were connected with the machine did not want paying during that week, and there were no upkeep charges, all would be well, but an aeroplane, unfortunately, required a staff of people to deal with it on the commercial as well as the technical side, whether flying or not. At the present time, if it were possible to fly all the year round as one could fly during June, July, August and September, the question of subsidies would not arise. Without a doubt the commercial efficiency of a machine would be actually increased by being able to carry more weight per horse-power, but that would not be a complete solution of the problem.

However, one did feel that the use of motor gliders, and the results that had been obtained with them, certainly marked a move forward in aerodynamical progress, and he hoped that we might look forward to a three-engined machine of this category, built something like the "Wren," when we could, with the extra horse-power available, perhaps be able to carry two passengers as well as the pilot. He hoped he was not too optimistic, and that, with that added security, a pilot would be able to fly in worse weather than he could fly in at the present time. There would be the added advantage that such a machine, being fitted with motor cycle engines, which were cheap, would not be so expensive to run or to maintain as some of the bigger machines with modern aircraft engines. Manufacturers of aircraft engines might look on them with alarm, but the manufacturers of the motor cycle engine might possibly be able to achieve the same kind of horse-power that the former could. In thanking the lecturer for his paper, Mr. Handley Page said that when one saw the original pictures of the Wright machines, one realised how old an experimenter he was and the immense amount of technical work he had done for the aeroplane and for its development in this country; the country and the Society owed him a great deal for the part he had played in the development of aviation in this country.

The CHAIRMAN said that Colonel Ogilvie had taken them back to pioneer days and had shown his connection with the first gliders, and in other respects the paper had indicated a going back to the past in a beneficial sense. It might be quite true—and he agreed with Mr. Handley Page in this respect—that if we tried to do anything we are doing now with gliders on a larger scale we should get back very nearly to where the commercial aeroplane is at the present moment; on the other hand, he believed some improvement was obtainable and that the improvement was worth having. It might, for instance, have kept the Schneider Cup in this country. One thing had struck him during the lecture as worthy of special note. From the point of view of getting valuable scientific information from the coming trials at Lympne it was desirable to know the horse-power of the engines. Colonel Ogilvie had said—and the point had been emphasised by Major Gnosspelius—that the horse-power of a particular engine was not accurately known, the various estimates varying by as much as 33 per cent. Whilst Colonel Ogilvie had put the horse-power at 14 or 15, Major Gnosspelius had put it at 24 or 26, and if the output of an engine is unknown to within 33 per cent., that particular factor was useless in a competition to determine the most efficient glider, for the differences between the best and worst would not be so big as 33 per cent. He did not see why it should not have occurred to the makers of these aeroplanes or to the people who were to test them, that the glider, with its engine, was almost ideal for the purpose of measuring the power of the engine. It was comparatively light, with a maximum weight of something of the order of 600lbs.; it could be hung from the roof of the hangar on two or three wires and

the whole arrangement, with the airscrew running, became an admirable torque reaction balance. That was a method of measuring horse-power which we knew to be accurate and which was our best standard method. He hoped that before the end of the trials some means could be taken of finding out, in the case of all the machines that made any show in the air, exactly what horse-power was developed in each case for given revolutions of the airscrew. With regard to control, he was not quite sure whether it was clear, from what Colonel Ogilvie had said, that he was not looking for startling developments in control at all or whether he confined his remarks to the coming trials. His (the speaker's) own impression was that the startling improvements in the aeroplane of the future would come in its control. Commercial aviation could not afford to leave the question of control in its present position. It was well known that if a pilot —a careful, skilled pilot—came to a difficult landing, he wished, of necessity, to come down at the least possible speed, because that made the bump at the end so much less. But if, in attempting to get that least speed, he made a slip—instead of flying at 50 miles per hour he flew, say, at 45—then there was all the difference in the world between the controls of the aeroplane as he intended to have them and as he had actually got them. For some seconds—it might not be very long, but for seconds, at any rate—he was powerless to control his machine. The sequel was well known; one wing went down and a spinning nose-dive was initiated. There was no danger in the spinning nose-dive at an altitude of several thousand feet. Every pilot knew just how to move his stick and how to recover; the manœuvre required to recover from the spin was, first of all, to push the stick forward, *i.e.*, to keep the machine in the dive, to reduce the angle of incidence, as a result of which the machine would stop spinning, gather speed and fly. A spin low down was dangerous just because there was not sufficient time to carry out the manœuvre. Measurements had been made as to the height necessary for complete recovery, and he believed that no aeroplane, not even the most controllable, could be trusted to recover from a stall in less than 500ft. fall of height. That was a serious state of affairs and one to which this country was directing attention, and he expected that in the near future, depending to a large extent on the facilities provided by the Air Ministry, it would be possible to so re-design the controls of an aeroplane and the aeroplane itself that it would be controllable when stalling. If the engine stopped the pilot must come down, but he believed it would be possible to give the pilot so much control over his machine that he would come down on his wheels and not on the front of the machine. This work is not essentially furthered by the forthcoming trials on light planes, the main object being the development of high efficiency. For the sake of the general progress of aviation it was desirable to devote as much energy as possible to the problem of reducing the head resistances of aircraft, a problem to which the construction of the light aeroplane seemed to be admirably adapted. Finally, he congratulated Colonel Ogilvie on his energy in getting his collection of slides together at such short notice, and also on giving the meeting one of the earliest pieces of advance information on the subject of low-powered aeroplanes.

Mr. R. K. Pierson (Messrs. Vickers, Ltd.) said that one point which occurred to him was that the weight per horse-power was too low. Assuming the weight of the aeroplane to be about 500lbs., every horse-power lost in the engine, due to faulty running, etc., reduced the rate of climb about 40ft. per minute. The rate of climb of the average light aeroplane was about 200 to 250ft. per minute, which meant that if the engine were 6 h.p. down it would be impossible to climb and if the load per square foot were reduced to overcome this it would be very difficult to fly in gusty weather. A light wind would take the machine off the ground.

With regard to the horse-power of the engine, he believed a particular Douglas engine was giving about 19 h.p. at 3,300 revs. per minute. He was using a propeller on that machine which was a small scale reproduction of one

used on a Napier Lion motor, and although the scale effect was unknown, the h.p. worked out to about that figure from the torque curve.

Colonel OGILVIE, in reply to the discussion and referring to the Chairman's remarks about control, said that what he meant was that he did not imagine that we were going to advance the solution very much in the coming competition; but, of course, one could not tell. Certainly one man, who was in great difficulty last year, had improved his machine with a view to getting better control over it. So far as he could understand, there was likely to be a very severe rush as soon as the weather was calm, but he trusted that it would not be too calm. That day he had received news that there was to be a competition for altitude, for a prize to be offered by Sir Charles Wakefield for the best height attained. He was very pleased to know that, because he had always felt that there was a serious lack of stimulus to the climbing of these machines, and climbing was one of the most valuable features; in fact, from the commercial point of view, climbing from the ground was the most important. As to the percentage of engine weight, as far as he could make out, the percentage of the total machine which the engine, tanks and fuel comprised was certainly very low—something in the neighbourhood of 15 to 20 per cent. on these machines. For structure percentages, such figures as he had were 40, 48, 55, 45 and 50, which he had estimated from the figures given him by different people. As regards the power of the engines, which Major Gnosspelius had referred to, he should have thought that with a light aeroplane one would have had an extremely good chance of measuring it. Dealing with Captain Hill's remarks as to control, Colonel Ogilvie said that what he himself meant was that he did not consider the control of any aeroplane to-day was good enough, because of this question of stalling and uncertain action of the machine. It was quite different from what the pilot ought to be allowed to have. Pilots put up with it, however, quite customarily and without thinking about it, but it was not good enough, and certainly not good enough to allow of the general issue of small machines to the public. Captain Hill was particularly interested in control and, in fact, had been engaged for some time on the design of a special machine which should have a much better control and which should not be prone to stalling or spinning; he hoped he would be successful with it. As to the gliding angle of the "Wren," he believed he was about right in saying that, as far as we had got at the present time, the angle was about 1 in 9 at top speed and 1 in 14 climbing. We ought to get higher lift over drag ratios in climbing at top speed.

A hearty vote of thanks was accorded Colonel Ogilvie at the conclusion of the discussion.

THE DESIGN OF MARINE AIRCRAFT IN RELATION TO SEAWORTHINESS

BY FLIGHT-LIEUTENANT D. F. LUCKING, R.A.F.

The present paper is an attempt to describe the disabilities from which various types of marine aircraft suffer in regard to seaworthiness, and its scope is limited strictly to that laid down by the title.

Some notes made by the writer formed the basis of a discussion at which were present several officers who have had very valuable experience in the handling of marine aircraft under all conditions. It was then remarked that there was more agreement upon controversial points than might have been expected, and the task of recorder is therefore comparatively simple. The greater part of the matter which follows has, however, come from other sources, such as Aeronautical Research Committee reports, and the technical press.

Qualitative data only is available to any extent. Full scale experiments to obtain a quantitative solution of some special seaworthiness problem have hitherto been few and far between (25), and improvement in this respect cannot be looked for in the near future. The sort of information now available, and which is constantly being supplemented, is in the nature of the observations and experience of the users and manufacturers of seaplanes. It might be mentioned here that the term "seaplane" is frequently used in its generic sense of including all kinds of marine aircraft.

A large amount of model work has been done, and the most important part has been in regard to water resistance and stability under way. It is not purposed to go into the question of resistance in any detail, as this can be studied at first hand in the Aeronautical Research Committee reports. Other special branches of research, that of corrosion for instance, although possibly included in seaworthiness in the broad sense, cannot be done anything like justice to in a paper such as this, and are therefore not touched upon.

The possibility of constructing a seaplane or flying boat to be seaworthy in the sense that a ship is seaworthy is not in sight owing to the amount of what a seaman would call "top hamper" which it is impossible to stow away or even, as a last resource, to jettison. The only thing that can be done in this way is to fold the wings towards the tail or in some other way. At present this folding operation is done to save storage space and is not carried out afloat as a rule. It does not reduce the exposed surface, but may improve its disposition. In any case it is doubtful whether the additional weight and complication can be afforded in the case of large types. The results of carrying out the folding operation afloat in the case of certain seaplanes during the war were so unsatisfactory that the practice had to be forbidden owing to the risk of capsizing stern foremost.

It must be realised at the outset that many of the more obvious means of improving the sea-going qualities of marine aircraft may not readily be adopted for aerodynamic reasons. Lowering the centre of gravity for instance—a question which will be enlarged upon later. Another obvious solution of all seaworthiness problems is to build very large machines. Even if such a course were theoretically justifiable (1a), it would be undesirable to take it at the present time owing to the expense involved with each separate experiment, and systematic research with smaller types should provide data for the elimination of radical weaknesses before very large designs are commenced. However, so far the theorem that seaworthiness improves with unlimited increase of size lacks that completeness of proof in the case of aircraft which holds good for ships, and which practice has confirmed as far as these are concerned.

The term "seaworthy" as used hereunder is to be understood as meaning comparatively so. As far as can be seen at present, even greatly improved aircraft will have to make use of their relatively tremendous speed to return to port when warned of the approach of really dirty weather.

Unfortunately, the maximum duration of heavier-than-air craft is insufficient to enable them to remain in flight long enough to outlast a disturbance, though it is satisfactory to observe that the length of life of a disturbance is usually of opposite measure to its severity. Against this is the fact that the swell following a gale is often of some persistence. A seaplane may therefore be able to alight only with difficulty and quite unable to take off for some time after the air has become relatively calm.

Some of the more elementary but not universally known characteristics of marine aircraft will now be outlined.

In order to maintain a satisfactory clearance between the propellers and the water line a high centre of thrust is essential (2*a*). Matters are made rather worse in this respect because a seaplane propeller has a larger diameter and smaller pitch than flying problems demand (25). This is in order to provide a large thrust below flying speed to assist taking off. Aerodynamic requirements, however, necessitate an approximation of the thrust line to the centre of gravity. So that it follows that a high centre of gravity cannot be avoided. Therefore the only way to secure a positive metacentric height is to distribute the buoyant components.

The provision of an adequately lengthy hull or float to give a positive longitudinal metacentric height presents little difficulty, unless the wings are folded; but wind effects on the aerostructure necessitate a considerable lateral metacentric height. In the twin-float seaplane a satisfactory dimension may be obtained by making a sufficiently widely tracked undercarriage. In the ordinary single-float seaplane or flying boat the metacentric height of the hull alone is negative, and therefore small floats attached to the wing tips are necessary (3). The effect of even slight immersion of one wing-tip float is to displace the centre of buoyancy considerably over to that side so that the metacentric height becomes positive. Alternative methods of reaching this end are discussed later.

Here the deduction might be made that because the thrust line must be kept as low as possible consistent with adequate water clearance, therefore it will be necessary to develop multi-engine craft, each engine with its own propeller—that is to say, one should have two or more small engines and propellers rather than one big engine and propeller. Against this, however, it might be said that it is easier to shield a single than a number of propellers by using the hull or floats as a screen between the water line and the propeller disc. In addition, moments of inertia are increased by separating the engine weights.

If a smooth-bottomed hull such as that of an ordinary motor-boat is propelled at high speed through the water, it tends to suck down by the stern and increase of power will make practically no difference to the maximum speed attained with a given hull. In racing motor-boats and in aircraft this difficulty is overcome by breaking the continuity of the hull bottom and making a definite step, so that the bottom ends abruptly and then restarts an inch or so higher up. It is essential that air should be allowed to reach the space just abaft the step either by leaking in past the chines or by means of ventilators (3, 5, 6, 7). When a certain speed is reached, the water breaks away from the hull bottom abaft the step, and hydroplaning commences. Considerations of stability when hydroplaning as a rule necessitate more than one step being fitted, and up-to-date practice favours a main step in the neighbourhood of a vertical line through the centre of gravity and one auxiliary step aft, an arrangement tantamount to that of the conventional disposition of flying surfaces (3*a*).

A considerable amount of model research has been carried out in the Froude tank at the N.P.L. Probably the most valuable results obtained have been in

regard to the maintenance of longitudinal stability when under way (10, 11, 12), and to low resistance shapes. In some ways, model tests are unsatisfactory, such as :—

(1) When a model hull is run at the N.P.L., it has been customary to allow for the wing lift by assuming it to vary as the square of the speed, and by the use of counter-balance weights accordingly. This method is faulty in that it does not allow for the effect of variations in incidence on the wing lift, nor can the conditions during acceleration be reproduced. It would appear that better results might be obtained by the use of a small submerged plate appropriately attached to the model hull. It is believed that something of this sort has been done in the U.S.A. (18).

(2) Much of the spray which appears innocuous in a model test is, in the full scale, caught by the wind and propeller with destructive results.

(3) A revolving propeller not only catches any spray that is going, but actually sucks up miniature water spouts, which are quite large enough to be a nuisance. This effect is not seen during a model test.

(4) The actual manœuvres of getting off and landing cannot readily be imitated by a model.

(5) It calls for craftsmanship of a very high order to ensure that a model and its prototype shall be geometrically similar to the order of accuracy required. A difference between model and full scale behaviour has been traced to slight discrepancies in form in one case at least.

The water resistance of a stepped hull or float increases up to a point and then decreases as the speed is gradually increased. The failure of early types of marine aircraft to " unstick " was usually due to insufficient power to get past the hump in the float resistance speed curve. The hump occurs at a speed less than that of hydroplaning. When hydroplaning occurs the craft virtually ceases to have displacement, the weight being supported by the water reaction on the planing bottom of the hull or floats and by the wing lift. As the speed increases the wings gradually take over the load, and the wetted portion of the hull bottom decreases in area.

The porpoising of marine aircraft when hydroplaning is probably analogous to the slow speed or phugoid oscillations of a machine in flight. After it has been initiated this pitching oscillation as a rule tends to increase in amplitude and may become dangerous. It is chiefly dependent upon the positions of the steps and the contours of the hydroplaning surfaces.

A good many variations of the features referred to above have seen service, and a short description of the nature and characteristics of some of them may be useful.

The single-step planing bottom is exemplified in the Short and Fairey seaplanes of which the main floats terminate with a broad heel, forming what is effectively a step if not actually so, so that this type of float is sometimes called " stepless." A stern compartment with a raked-up bottom of no hydroplaning significance, but useful in providing tail buoyancy, is sometimes added to such floats, which then become " single-stepped " floats.

The modern N.C. flying boats and the early America, from which the F boat was developed, are single-stepped types; but F.5 has two steps—a main step about three feet abaft the centre of gravity and a tail step seven feet abaft the main step. Both steps terminate planing bottoms which show as straight-sided vees in the body plan. In the case of the F.5 the term " tail step " is misleading, the arrangement being really that of tandem main steps.

As mentioned earlier, a small tail step is now as a rule added well aft to act as a stabiliser to the main step. This form of two-stepped hull may be made to

hydroplane at all speeds with little or no porpoising tendency and is becoming popular for this reason.

In favour of the single-stepped or tandem-stepped types, and against the stable type, it is often said that the former possesses a wide range of trimming angles which a skilful pilot may use to advantage, particularly in rough weather (25). On the whole, pilots seem to think little of this argument, as owing to paucity of air control the water forces cannot be overcome except when hydroplaning in the neighbourhood of the flying speed, and then only with difficulty. Viewed solely as a hydroplane, a single-stepped seaplane may possess neutral stability, but in general is unstable and porpoising has to be damped by the action of the tail plane and elevators. One can infer from this that the single-stepped type of hull or float is suitable for smaller rather than larger craft.

The successful development of the stable two-stepped hull is due to model research at the N.P.L. The best form arrived at so far has the forward or main step in the neighbourhood of the centre of gravity—that is, further forward than the F type and the interstep distance two or three times that of the F type. Both planing bottoms show as hollow-sided vees in the body plan. In the sheer plan the two steps are arranged so that when hydroplaning the craft trims at the most favourable attitude for getting off. Some tendency to porpoise may still exist in this type, but occurs, if at all, at so high a speed that it is damped automatically by the aerostructure without the pilot using the elevator control.

A very large potential buoyancy seems to be necessary to give cleanliness at low speeds and low water resistance, and attempts to reduce hull sizes have not so far been successful. Existing float seaplanes have a potential buoyancy of from two to three times the displacement; in other words, a reserve of buoyancy of from 100 per cent. to 200 per cent. The similar figures for flying boats are greater, principally owing to the necessity for sufficient free board to keep green water from the cockpits and because the tail unit is carried by an otherwise unnecessary extension of the hull proper (*2d*, *3b*, 9, 13).

Consideration of first principles might lead one to conclude that it would be impossible for an economical aerostructure to stand up to water shocks. The relation between the two densities is of the order of 1 to 800, so that the velocities will have to be inversely as the square root of this ratio for water pressures to remain as low as air pressures. That is to say, that water moving at more than 1/28th of the flying speed may produce greater pressures on the aerostructure than occur in flight. Put in another way, one per cent. of water in the air will increase the unit loading to eight times (26). However, it should be realised that water shocks, to anything except the hull, will only be local as a rule, and therefore stress the skin or covering and ribs rather than the main structure. It seems probable for this reason amongst others that that form of cantilever wing construction in which the skin takes the major stresses will take an important place amongst design developments on the marine side. Designed to this end, the skin will probably be heavy enough to withstand severe local stresses due to water forces. With conventional methods of construction one must be content with a craft of which the aerostructure cannot stand up to water shocks and must therefore be kept as free from them as possible.

The lower plane and elevators of marine aircraft are most vulnerable parts. The former more particularly in flying boats and single-float seaplanes; the latter in the case of tail-floated seaplanes which lie very tail down at rest or during slow speed taxying. The effect of severe water shocks is to tear the fabric and to break or bend the trailing edge and ribs. Damage to the main spars does not usually occur. Cases have happened when the crew of a flying boat have judged it expedient to cut away the fabric of the lower plane after a forced landing in bad weather. This is done to allow the seas to break through the plane structure freely, so causing it to be subjected to less severe blows. The lower plane cannot

well be raised so that the reduction in size and boat-building of this component is receiving attention. Owing to the moving control surfaces of the tail unit, boat-building it alone would not be a sufficient protection as the series of fittings from the elevators and rudder to the control column and rudder bar have also to be considered. Also minor damage to a control surface may more readily have serious results in flight than that occurring to a fixed surface. In consequence, the only thing seems to be to keep the tail unit as high as possible. Open cockpits may be fitted with canvas covers when afloat in bad weather, and these are not unsatisfactory apart from the trouble of fitting them under difficult conditions.

Lack of seaworthiness may be betrayed in many different ways, according to the speed at which the craft is moving and the manœuvre which is being performed.

When lying at rest the aerostructure, particularly the lower plane and tail unit, may be damaged by receiving water shocks, while the cockpits may be swamped. When taxying at a slow speed the nature of the conditions changes from that at rest, chiefly in that the bows of the hull or floats give rise to a wave formation and spray, from which the propellers and crew may suffer. Diving may occur at low speeds with a big sea running (3, 3*b*). In general terms the tendency to dive is inversely proportional to the length of forebody. In smooth water and with a normal load, a machine will trim slightly down by the nose as it moves off from rest owing to the high centre of thrust. Taxying with a beam wind is unpleasant for the crew in the nose of a flying boat hull, which is usually very wet under this condition. As the speed is increased, cleanliness forward is obtained as the forefoot lifts and the bow wave retreats aft. Under this condition and during the commencement of hydroplaning the bottom plane and tail unit are usually deluged with spray, but the propellers are running cleaner if well forward. During high speed hydroplaning, immediately previous to taking off porpoising may occur, but can be damped out more or less by the air controls. The loading on the hull bottom is locally severe under this condition, but less severe than that due to a heavy landing.

The result of a bad landing may be the breakage of almost any part of the structure according to the nature of the fault in the manœuvre. Rather unexpectedly wing-tip float failure is not uncommon in this connection (22*c*). The rigidity of the interplane trussing and the fact that wing-tip floats are not as a rule sprung in any way may account for high impact stresses being reached. There is always a risk of waterlogging a wing and capsizing if a wing-tip float goes; but, in service, flying boats have been brought in safely with only one sound float (22*g*).

If a nose-down landing is made owing to an error of judgment, diving usually occurs and the machine is badly crashed (3, 3*b*). The results of a pancake landing are not as a rule so disastrous.

Important to remember is that a bad landing may injure a craft in such a way as to make it succumb when riding out afterwards, and a final test of seaworthiness may be the ability of the craft to remain afloat when holed. A partial loss of buoyancy may result in a loss of trim sufficient to cause further flooding.

Nevertheless, it has been found by experience that taking off is the most difficult operation under adverse conditions, and the ability for a craft to carry this out successfully is the principal criterion of its value in service.

It has been found by experience that when taxying with a big sea running it is necessary to go dead slow, otherwise one wing tip dips into green water. This may be due to an unbalanced water drag checking one wing and causing the machine to yaw so that the lift of the arrested wing is decreased. The heel so initiated makes matters worse. This digging-in tendency is probably encouraged by the shape of the nose of the conventional aerofoil profile with its heavy top camber.

It is noteworthy that in one direction only—that of hull flexibility—has there

been a serious attempt made in this country to improve radically the seaworthiness of the larger flying boats since the advent of the early America type of twin-engined boats at the beginning of the war. From this type the F.5 and more recent and larger types have been developed chiefly by increase of size and minor alterations.

The very serious difficulty of making a float or hull structure light enough not to handicap performance unduly and yet capable of withstanding severe water shocks without failure is not perhaps fully appreciated by those inexperienced in the construction and use of marine aircraft (*3d*), though it may be remarked in passing that the actual air performance of flying boats is very little inferior to that of the average aeroplane under identical conditions of useful load. A flexible hull of the Linton Hope and Supermarine types has a bottom that is capable of considerable vertical movement in relation to the remainder of the structure, by this means obtaining a shock-absorbing capacity. As in other engineering structures, this makes for lightness. The nature of the construction is such that great skin strength is given to the hull by means of considerable wall thickness and closely-pitched timbers and longitudinals, but there are no rigid frames, which are replaced by hoops. The transverse sections of the hull are usually circular or nearly so. Flexibility and shock-absorbing capacity are not the only advantages possessed by this type. In addition, a better distribution of stress is obtained owing to structural homogeneity.

One of the theoretical objections to the use of flexible hulls which does not seem to be borne out by practice so far is that of the rigidity of the main plane structure carried by the hull. This objection would not appertain if the aero-structure were only a simple pin-jointed frame in which the hull would take the place of one or two members in each truss, but the conventional wire-braced box girder with its continuous spars can only allow for the panting of the hull by spar flexure and the working of ostensibly rigid joints. However, the writer has heard of no case so far in which the attachment of a rigid interplane structure to a flexible hull has been attended by the unsatisfactory behaviour of either, with the exception of the case of the first Phœnix Cork flying boat, of which the main planes became "soggy" after very little flying. This trouble did not re-occur with a new set and is therefore thought not to be connected with the hull design. It may be argued, but only by those without personal experience of the manifestations of hull flexibility, that the foregoing shows that the hull does not really pant to any extent.

It may be mentioned here that even with the so-called rigid hull the bottom deflects upwards, locally causing considerable strains and tending to open joints. During some purposely badly-made landings in an H.16 type of flying boat a deflection of $\frac{3}{4}$in. relative to the keelson was measured at a point midway between two floor beams at a distance of 18ins. from the centre line. The floor beams were pitched 14$\frac{1}{2}$ins. The maximum deflection occurred about 6ft. forward of the main step (*21*).

One serious trouble that has occurred with flexible hulls has been caused by attaching too rigid an outer or hydroplaning bottom to the flexible body of the hull. As might have been expected, this has repeatedly resulted in local failure of the outer and rigid bottom in the neighbourhood of the main step. There seems to be no reason why this trouble should not be overcome.

It should not be forgotten in connection with hull design that not only upward but also downward forces are experienced. Bottom suction occurs when a craft gets off at a low water speed, owing to meeting a head-on gust for instance. It probably occurs locally under quite normal conditions, but cases are not unknown in which a seaplane has got off and left both float bottoms on the water (*18*).

Primary failure outwards, as described above, has not occurred, within the

writer's experience, to a flying boat; probably the vee bottom which nearly always forms a feature of boat rather than float design is advantageous in this respect.

An interesting summary of the merits of flat and vee bottoms is that the first gives a quick take-off and consequently a lessened risk of damage during the process. A vee-bottomed hull with its greater water drag gives a longer get-away run but a much softer landing (3*c*, 3*d*). Another disadvantage attendant on the vee bottom is that it throws up more spray than does a flat bottom, and the steeper the vee, the higher the spray (3).

It is now purposed to discuss the varieties of marine aircraft in common use.

Twin-Float Seaplanes

The twin-float type of seaplane is, in its present stage of development, little more than a single-engine tractor aeroplane on floats. This assertion has been contradicted by seaplane designers, who, perhaps, wish to claim more than a fair share of specialist knowledge, but its truth is made apparent by the fact that some firms offer essentially identical aerostructures with land or sea undercarriages to suit, and even as interchangeable components.

The outlines of the well-known Short and Fairey types are very familiar and need no description. The single-engined pusher type of twin-float seaplane seems to have disappeared altogether with the similar type of land machine, probably for identical reasons of poorer performance and greater vulnerability to attack from the rear than the tractor type.

In the tractor type the propeller disc is usually some six inches above the top of the floats at its lowest point, but between them. When taxying with the tail up, some two feet of clearance from the nominal water line is all that obtains, and it is obvious that damage from spray and from green water hitting the propeller must certainly and does in fact occur when the height of the waves approaches the amount of nominal clearance (4). This disadvantage carried with it the attendant propensity for the propeller to throw up spray, which is carried back and soaks the crew in the fuselage.

Owing principally to racking in both transverse and fore and aft directions, it has been found necessary to design the undercarriages of twin-float seaplanes with greater normal load factors than land machine undercarriages, and failure of the undercarriages or floats is usually literally a one-sided affair. The disadvantage of unsymmetrical float loading, of secondary importance in a small single-engined twin-float seaplane with both floats strutted to each other and to a common fuselage, becomes more serious when the larger twin-engined type with an engine over each float is considered. Then the two buoyant structures will be of such distance apart as to make the interconnecting structure of prohibitive weight, if of adequate strength. This disadvantage has latterly been assumed to outweigh the many attractions of the types from points of view other than that of seaworthiness. A comparatively recent and very large type of twin-float seaplane was the four-engine Zeppelin Staaken biplane. It is understood that one of the floats of this machine pulled off while taxying. Various British firms constructed twin-engined and fuselaged seaplanes during the war, but none of these was considered successful.

Twin-floated seaplanes may be divided into two main classes, according to whether they have tail floats or not. The tail-floated class may be subdivided into varieties differing by the extent to which the tail float is necessary in maintaining longitudinal stability afloat. Some have the main floats with sufficient buoyancy astern to keep the tail float clear under ordinary conditions; in others the tail float is partially submerged until hydroplaning commences (25).

This last variety possesses two distinct advantages which both spring from the tail down trim taken up at rest and not greatly departed from during slow-

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speed taxying. The greater freeboard and raked-up bottom forward renders the floats less liable to dig into green water and a considerable propeller clearance is maintained.

The class without a tail float but with long main floats possessing buoyancy abaft the main step may have two or more steps in each float. As a rule, however, the after-bottom is raked up and performs no hydroplaning duty. Little change of trim occurs over the whole range of water speeds, the craft always maintaining a tail-up attitude, so that the tail, more especially the elevators, is kept free from water damage, the liability to which forms what is perhaps the principal weakness of the tail-floated type.

There does not appear to be much demand for a two-stepped float seaplane having positive water stability when hydroplaning. The magnitude of both air and water forces is much less than with a large flying boat, and the sensitivity to air control greater, so that a neutral stability characteristic may even be an advantage.

There are one or two other points to consider when comparing the merits of the tail-floated, tail-down class with those of the long-floated, tail-up class. When drifting head to wind, the former presents its wings at a large angle of incidence, and the centre of gravity is well abaft the centre of buoyancy of the main floats, so that gravitational and wind forces combine to subject the tail float to a considerable live load which stresses the fuselage somewhat severely in anything of a lop (*22e*, 25).

It is sometimes argued that the long-floated type may be dangerous to land in a short sea because the after-bottom may make contact with the receding face of a wave while the main step is still clear of the trough (25). The inferred result is that the bows would dig into the face of the approaching wave. This point is weakened by the fact that a liability to perform such a feat is present in the short-floated type because it is necessary to keep the main step well aft in order to lift the tail prior to hydroplaning.

Two very real advantages of the tail-floated type are, firstly, that it is easier to handle on the slipway, as the after-end of the fuselage is more readily manhandled, and secondly, it is easy to fit a water rudder below the air rudder without complication of controls.

In the twin-float seaplane, the lower plane and cockpits are usually higher from the water than in the single-float seaplane or flying boat of similar size; but even when wing-tip floats are fitted, the wing tips and ailerons of the bottom plane often suffer when taxying.

Owing to the fact that their method of attachment permits springing, and that they are not used for the disposal of crew, the floats of a seaplane may be rigidly bulkheaded, thus giving a considerable factor against total loss.

While causing yawing to an extent which prevents getting off, partial loss of buoyancy in one of the main floats, or even complete loss of buoyancy in one float if the wing-tip floats are of sufficient size, will not cause further flooding, but serious damage to the tail float, or to the after-compartments of both main floats in the type without or with too small a tail float, might easily cause the craft to capsize stern foremost. Damage in this way is, however, comparatively unlikely to occur since these parts are, except in the case of floats which terminate with the main step, free from water shocks at high speeds.

From reasons of the small amount of freeboard forward, and the comparatively high centre of gravity, a seaplane is very liable to dig in the nose of the floats and to capsize forwards if flattening out previous to alighting is delayed a fraction too long. This may also happen if porpoising is allowed to become too violent. The pitching forward tendency of a float seaplane on landing due to the resultant force from the float bottoms passing abaft the centre of gravity used occasionally to result in collapse of the foremost undercarriage struts.

One of the most conspicuous disabilities of the ordinary twin-float single-engined seaplane is the difficulty of directional control when taxying at slow speeds at which the air controls are ineffective. A water rudder attached to the tail float or one attached to the stern of each main float should always be fitted; but even so the control is poor in a strong wind, into which the seaplane tries to weathercock. The steering trouble is fundamental and is due to the necessity of actually retarding one float and accelerating the other on a turn (14).

Single-Float Seaplanes

The type of seaplane having a central main float and maintaining lateral stability when afloat by means of wing-tip floats in the same manner as does a flying boat has never been developed in this country to any extent, and the only British representative of the type at present is a tractor machine fitted with amphibian gear. Unfortunately this craft was designed to a particularly stringent specification in the matter of overall dimensions, and therefore can only be compared to other types designed to the same specification, which was such as to make seaworthy qualities practically unattainable.

With a tractor design it is difficult to provide at once sufficient freeboard and propeller disc clearance forward. The question of propeller clearance is complicated by springing the main float—a very desirable feature with a flat-bottomed float. Springing may be avoided, however, by fitting a vee-bottomed float. When this step is taken three further disadvantages appear—firstly, the get-away run will be longer; secondly, it will not be safe to run the craft up on to a slipway (25); thirdly, the bow wave with its spray will be thrown higher.

With a single central instead of twin floats the propeller is certainly better protected from green water, but with a vee-bottomed float the spray is caught by the slipstream and flung back over the top plane into the fuselage cockpits.

The amphibian referred to earlier has a rounded bottom, of which the keel is very little lower than the chines. While certainly uncomfortably wet, this craft has a remarkably short get-away run.

Considering the main float alone, the metacentric height is negative and wing-tip floats are necessary. The lower plane has not therefore with convenience so great a lower plane clearance as a twin-floated craft.

An important difference between the rolling of the single as compared to that of the twin-floated seaplane is that in the first case the roll is more positively damped at the outset by the wing-tip floats, and therefore the craft does not acquire as great an angular momentum before the wing tips reach the water, whereas if the wing tips of a twin-floated seaplane meet the water, the contact is probably violent.

The alteration in trim resulting from a partial loss of buoyancy in the main float, which may be conveniently bulkheaded, would not be as a rule serious, but the loss of a wing-tip float would probably cause the craft to capsize, but not necessarily to sink, after the lower wing on that side had become waterlogged.

The pusher variety of the type has attracted little attention here, but in this case the propeller would be even more free from water than that of the tractor machine, and the crew in a drier position.

In other respects, the single-float seaplane resembles the twin-floated craft in seaworthiness characteristics, except in regard to steering when taxying. The single-floated machine here possesses a definite advantage owing to narrowness of track, provided a good water rudder is fitted, and the wing-tip floats are not carrying too much weight.

Single-Engined Flying Boats

From the point of view of propeller protection the single-engined flying boat is better off than the single-float seaplane owing to the hull of the boat being used for the disposal of the crew and other load, and therefore conveniently larger than the float of the seaplane. The crew, usually in open cockpits in the nose, are, however, worse off.

In regard to lower plane position and wing-tip floats, the type is in similar case to the single-float seaplane (15); but in regard to the tail unit, the proximity of this to the water line when carried as usual on the after-end of the hull is a serious defect.

Owing to the fact that most of the load is carried in the hull, no special shock-absorbing apparatus is fitted, and some successful examples of the type have embodied a flexible hull, to which the provision of suitable bulkheads is a difficulty which is receiving attention. At present, however, protection from total loss of buoyancy due to the hull being holed is provided only by means of a double bottom forward of the main step, so that flooding will only occur if both bottoms are pierced (2c).

The loss of lateral stability consequent to loss of or serious damage to one wing-tip float may result in total loss, owing to the hull being readily flooded through the open cockpits, so that if the machine capsizes it will almost certainly sink.

The question of whether to make a single-engined flying boat a tractor or a pusher has usually been decided from consideration of engine position with regard to centre of gravity, and the disposal of the crew in the nose of the hull has usually resulted in a pusher design which possesses a slight seaworthiness advantage in better propeller protection.

There are one or two instances of the type having been fitted with booms, as those of a pusher aeroplane, for carrying the tail unit. This has the result of enabling the tail to be kept higher from the water and of shortening the hull (19, 20). The saving in weight of the hull is, however, more than counter-balanced by the additional weight and aerodynamic resistance of the tail booms, so that this version of the type, though probably more seaworthy, has never become popular.

The signal weakness of the small flying boat is the wetness of the cockpits in any but the calmest weather. It is principally this characteristic which has made the type less popular than the twin-floated seaplane of similar overall dimensions.

The Twin-Engined Flying Boat

Of the various types of marine aircraft with which experience was gained during the war, the most seaworthy proved to be the Curtiss or America type of twin-tractor biplane flying boat, which later developed into the existing F.5, which may be taken as an excellent and representative design.

Originally the type was single-stepped and possessed a slab-sided hull (1). The earliest actually used on this side of the Atlantic, however, whilst retaining the single step, had watertight fins added to shorten the run to take off by increasing the hydroplaning area. The hull skeleton of the F.5 forms a rigid steel-clipped wooden frame. The single skin is built up for the most part of two layers of mahogany, but this is reduced to a single layer wherever possible. Watertight compartments are provided in the fins, and half-bulkheads at intervals athwart the hull rise to a height above the load water line, and while not interfering with intercommunication, these fulfil a limited service in providing against flooding. The sharpness of the vee bottom of the early Americas was increased

in later developments to reduce water shocks, and the original single step was replaced by the tandem arrangement described in the introduction.

A sharp vee bottom has, however, the result of increasing the length of the get-away run by increasing the resistance. This may readily be understood by regarding the hydroplaning drag as proportional to actually wetted area (2). Also, the sharper the vee the higher rises the spray thrown up by the blister.

The tail unit is mounted on the after end of the hull, and the single tail plane is carried some six or seven feet above the water line by means of a system of struts and the vertical fin. The engines are mounted rather higher than midway between the planes.

The propeller discs are forward of the leading edge of the lower plane, and extend slightly below it, so that during taxying they pick up a certain amount of spray from the fringe of the blister thrown up by the vee-bottomed hull (3*a*, 9). Serious damage to them is unusual but occurs sometimes (3*c*). The cockpits in the nose do not take in spray in a swell or in small waves, except when taxying with a beam wind, and when lying to it needs a very big breaking sea to swamp the hull.

The most conspicuous disability of the F.5 is the fact that the hull is unstable fore and aft when hydroplaning and the oscillations cannot wholly be checked by use of the air controls. The pilot is thus unable to hold the machine at the most favourable attitude for taking off.

Towards the end of the war a modified type of two-engined flying boat was produced in the Phœnix Cork or P.5. The hull of this type was designed by the late Mr. Linton Hope, and is of flexible construction. The hull volume is much less than that of the F.5, and this is the principal reason why the type is wetter when carrying a heavy load (16). With light loads the P.5 hull behaves as well or better than the older type (2). A double-bottom forward is used, and the main step is formed where the outer bottom is discontinued. That part of the hull included by the two bottoms is sometimes called the "step" (1), and is formed into fins at the sides, but fins which are much smaller than F.5 fins so that the hydroplaning area is also much smaller. The lines of this type of hull were a result of model research, and it possesses considerable advantages over the F type in regard to longitudinal stability under way. In addition, its flexibility enables it to withstand greater water shocks without failure. Its dirtiness with heavy loads is probably due to the water line meeting the bows high up where the buttock lines are bluff, and to insufficient freeboard.

The P.5 runs at moderate speeds with the water in contact with both steps and with the bottom between them. The tail step is vee-sectioned to lie in the furrow left by the main step, and running at a small but positive angle of incidence gives a slight lift which produces a moment balancing the stalling moments due to the lift of the planing bottom forward of the main step and to the slight suction which occurs between the steps (3).

In regard to wing-tip floats and tail units, the F and P types are very alike. The tails are carried so high as to be practically free from water shocks in ordinary weather, though this is done at the expense of a clean and economical structure. The wing-tip floats are bracketed to the lower plane spars at the outer interplane struts, and put stresses in these members which may be considerably greater than the flying stresses.

Repeated water shocks on the lower plane and transmission of acceleration and retardation forces between the wing, engine and hull masses have been followed by failure of the wing attachments to the hull in cases where a twin-engined flying boat has had to taxy in a heavy sea. The present tendency towards fuel disposal in the wings would be disadvantageous in this respect.

Watertight compartments are provided in the fins of the F type and the

double bottom of the P type boats, but bulkheads in the ordinary sense are not fitted for several reasons, chiefly of interfering with intercommunication, and in the case of flexible hulls, of a suitable design of panting bulkhead not being available.

Since the end of the war two British firms have produced twin-engined flying boats larger than the F and P types. In one case the firm concerned was without previous experience of marine aircraft, and F and P boat practice was departed from with unfortunate results, in that the first two of the type both crashed shortly after completion. The bottom of the first failed forward of the main step. It is thought that the second damaged its tail when taxying, and a defect was thereby occasioned which developed in flight and caused loss of control. Damage so caused had previously occurred to the first of the type, but not to any serious degree.

Only one example was built by the other firm concerned, and this met with some success. It did not, however, represent any great advance, beyond increase of size, over the F.5 type.

In each of the above cases the rigid type of hull construction was retained.

The writer has little information relative to the capsizing of the larger types of flying boats, and it is believed that the rare cases of total loss have been by settling in a more or less normal attitude.

A water rudder is not nearly so essential a fitting on a twin as on a single-engined machine, as the engines may be used for turning in the former case. But the necessity of opening up one engine may be undesirable for several reasons —the acceleration of one wing tip against a heavy sea might be mentioned—so that in any case a water rudder is nearly indispensable.

In conclusion, there is one point of immediate interest in connection with the use of the F type flying boats for anti-submarine patrols during the war by the Felixstowe squadron. The seaworthy qualities of this design are such that not a single life was lost owing to any fault in this respect (*3d*, *22a*).

Multi-Engined Flying Boats

Multi-engined flying boats first appeared here with the Porte baby—a three-engined machine. It was not a great success in the air chiefly owing to heaviness and sluggishness of control, but handled comparatively well on the water. On one occasion one of these craft was taxied across the North Sea from the Belgian coast to Felixstowe without suffering damage of any sort (*22b*). It was followed by the Porte Super Baby or Felixstowe Fury, the latter being the official name. This boat had five Rolls Royce Eagle 8 engines, and was a triplane with the tail carried on the stern of the very broad hull. Wing-tip floats were carried on the bottom plane as usual. It was found inadvisable to carry out heavy load trials with the Fury owing to the fact that she hydroplaned too easily and was too liable to be thrown into the air at less than her minimum flying speed. This was probably the indirect reason why she finally crashed. In any case, it is indicated that if it is necessary to use a very broad hull, then means must be taken to render some of the potential hydroplaning area non-effective (*26*).

The only German examples of the type of which details are available were made by the Dornier firm, and were very nearly " all-metal " machines. It may be of interest to note here that, on the authority of a statement made to the I.A.A.C.C., 100 tons of nickel steel was used for the wing spars, and the wing weight per square foot was of the order of 1 lb.—a very low figure for such large craft. This data should, however, not be accepted without verification.

The first Dornier boat was the R.1, a three-engined pusher with Warren girder interplane trussing. The tail plane and elevator were mounted on the hull

with only a small water clearance, and probably for this, among other reasons, this experimental boat was not a success. In other respects the craft was not dissimilar to the America type (17*a*).

The second Dornier, the R.2, embodied the lessons learnt from the R.1. The necessity for wing-tip floats was avoided by giving great beam to the hull, which contained three engines driving three propellers through gearing. This latter arrangement was replaced in the R.2a by tandem pairs of engines in nacelles with directly-driven propellers. The top plane was of considerable span, but that of the lower plane had been cut down to equal about half that of the top.

The R.3, the next development, differed from the R.2 chiefly in having the tail booms replaced by a fuselage carried above the single plane—a considerably cleaner form of design. The tandem power units were retained, but the small lower plane was dispensed with.

The fourth Dornier multi-engined boat was generally similar to the third, but the lines of the hull were different, and the R.4 had elementary bottom wings on the water line providing buoyancy outboard for assisting lateral stability.

The R.1 and R. 2 had cut-water entries to their hulls resembling those of the Norman Thompson boats here. In the R.3 the sharp but nearly vertical stem was discarded, and in the R.4 the bows were further modified to a form not very different to that of the floats of the familiar Short and Fairey seaplanes (17*e*).

The American three and four-engined N.C. boats had a wing structure resembling that of the F type, but carried their tails on booms. This latter measure seems to have been taken without full realisation of its possibilities, as biplane tails were fitted with their lower portions little better off in regard to water clearance than if they had been mounted directly on top of a longer hull. No fins were fitted to the vee-bottomed hulls, which had no greater beam than has the F.5, in spite of an increase of gross weight from about 13,000 lbs. to 22,000 lbs.

The bows of the N.C. boats were not bluff like those of the F boats, but had vertical stems. The forefoot, however, was above the l.w.l., so the vertical stem could have little effect on the running.

A rigid form of construction was adopted for the N.C. boats. Taken in order from the bottom up, the following members took the load consecutively:—

(*a*) 45deg. outer skin.
(*b*) Thwartships inner skin.
(*c*) Longitudinals.
(*d*) Bulkheads.
(*e*) Keel, chines, etc.
(*f*) Wing spars and struts.

The Hydrovane

From time to time experiments have been carried out with submerged cambered planes, usually called hydrovanes, instead of using the hull bottom as a planing surface (4). Work on this problem was done by M. Forlanini, M. Santos-Dumont and Commander Burney with the Bristol Co., before the war, but it is believed only the last of the three named applied the principle to aircraft. In some ways the suggestion is attractive. For instance, the landing shocks might be restricted to a few members specially designed to take them instead of being spread over a large area as at present, because the necessary hydrovane area is very small. One of the difficulties experienced with large flying boats is getting off in a long swell (3*c*). After the boat has passed over the crest of a wave it tends to leave the water even if flying speed has not been attained. Then the water lift being lost the boat pancakes down again. There are certain arrange-

ments of hydrovanes which should prevent this trouble, the planes being superimposed vertically so that they successively leave and enter the water. In other words, the lift obtained from the planing bottom of a hull varies too rapidly with vertical movement of the water line. It is possible that a hydrovane system may be designed to give a gradual change of lift over a range of vertical movement of water line of several feet with aircraft not larger than the flying boats in use.

There are, however, many difficulties, the more important of which may be mentioned.

The projection of the hydrovane and their struts below the bottom of the hull prevents the use of the usual trolleys and slipways so that the craft must either remain afloat or the hydrovane must be collapsible in a somewhat similar manner to the wheel gear of amphibian aircraft. Probably the first solution might apply to large and the second to smaller craft.

The problem of maintaining longitudinal stability on the water as well as in the air is complicated by the necessarily high thrust line. By suitably arranging the tail surfaces in the slipstream the flying problem is solved fairly satisfactorily. The hydrovane case does not appear to be so simple. It might be possible to arrange the main hydrovane or vanes so that the mean resultant passes as near as possible to the centre of gravity and to balance the thrust couple by means of a controlled tail hydrovane which could leave the water earlier than the main hydrovane. The final movements of taking off would be carried out by means of the air controls.

Stability in roll whilst taxying is not easy of solution owing to the small area and span of the main hydrovanes. In these circumstances a large dihedral angle on the hydrovanes may have an opposite effect to the dihedral angle on the wings, being equivalent to a vertical fin below the centre of gravity. If the main hydrovane is bisected and a half put under each wing the racking stresses and strains are likely to give trouble.

It is understood that Commander Burney overcame the rolling trouble by fitting vertical rudders below the main hydrovanes which could be controlled to produce a yaw to correct a roll.

Directional stability on the water does not appear to present any difficulties and it is doubtful whether the effect of wind across tide would be any more serious than with existing marine aircraft.

Recent Developments

Post-war versions of flying boats by the Roland and Dornier firms in Germany resemble each other to some extent. In both cases the conventional lower plane with its wing tip floats is dispensed with. In the case of the Roland, as in the later R.2 and R.3 described above, a hull of great breadth is used. In the case of the various Dornier designs the rudimentary lower planes of the R.4 have been retained, but their span is such that they can hardly be regarded as more than exaggerated fins. These craft are said to be remarkably seaworthy (24). In another direction the Roland designer appears to have sought improvement. The freeboard forward is greatly increased so that the pilot in the forward cockpit is well above the bows, which are very bluff in plan form.

A very notable suggestion has recently been put forward and patented by Mr. Manning, who was responsible for the general design of the P.5 flying boat. The proposal resembles the Dornier design in having bottom planes to maintain lateral stability on the water, but there are important differences. The Manning proposal is to construct the stabilising wings with their roots below the waterline, and with a pronounced dihedral angle, so that when the craft heels over on the water the immersion is progressive outwards instead of inwards as with a hori-

zontal plane which will obviously dip its tip first. This modification is to prevent sudden loading at the tip, which stresses the structure severely as well as causing the craft to yaw unduly. It is particularly in alighting that the Manning hull should show its advantages as this is the condition under which the wing tip floats of a flying boat have as a rule failed. The progressive immersion outwards of the Manning bottom plane replaces the suddenness of contact of the wing tip float bottoms as the hull sinks into the water.

The Manning wings in span and profile much more nearly resemble conventional wings than do the Dornier wings, which can contribute little lift to the structure owing to their poor aspect ratio.

Model tests have been carried out and have given promising results. It is believed that the construction of a full-sized machine has been commenced.

Some Details of Design

There are about four distinct types of bow design of hulls and floats with which experience has been gained and this part is most important as far as keeping dry is concerned, whether the type is a float seaplane or a flying boat.

Firstly, there is the square-ended type of which Short and Fairey floats are examples.

Secondly, there is the cut-water entry possessed by the Norman Thompson and Vickers Viking boats.

Thirdly, there is the rounded nose of the F type boats.

Fourthly, there is the type represented by the Phœnix Cork and Supermarine A.D. boats.

The last named firm has, in its single-seater and Seagull designs, produced a bow form with fin modelling apparently based on some of the earlier N.P.L. tank tests. This departure seems to have effected a considerable improvement at low-water speeds.

Looking at the various longitudinal sections or buttock lines of a hull from the centre line to near the chine it appears that the water line should meet the bottom line at the smallest possible angle. If the water meets the bows at a coarse angle, experience has shown no reasonable amount of flair or freeboard will keep the spray from the splashes from reaching the forward cockpits. In addition it appears to be necessary to have breadth and length of forebody and depth of freeboard forward in order to prevent digging in and also breaking seas from pouring into the cockpits (3*d*).

A cut-water entry consisting of a nearly vertical stem does not appear to effect much improvement, at low speeds, to a hull of which the buttock lines are bad, and it seems unnecessary when the buttock lines are good (5), as in any case the forefoot is running clear at hydroplaning speeds. In addition the extra side surface so far forward introduces aerodynamic complications (11).

Briefly, it might be stated that fine buttock lines are more important than fine plan lines. It is the writer's opinion that the Short type of float nose and the " F " type of boat nose are the most seaworthy that have been evolved in their respective classes.

The Manning version of the partially submerged wing in its present form is set rather far forward on the hull, which was found necessary in the model tests, and has only a slight rake aft. For aerodynamic reasons the position of the top plane is fixed abaft that of the lower so that a negative stagger results. This feature has structural advantages since the interplane trussing is nearly parallel to the mean resultant force on the wings in normal flight, but tends to increase autorotation. It is suggested a more comprehensive series of model

tests than have yet been carried out would be very valuable to elucidate the effect of variations of bottom plane dihedral and aspect ratio on the water stability.

From experience gained with existing types of flying boats it appears to be necessary that, for low speeds, the hydroplaning area should be the maximum possible to obtain cleanliness and that, for high speeds, it should be a minimum to prevent the water forces from throwing the machine into the air at less than a safe flying speed (*22d*). Research into the variants in hull design affecting this question is urgently needed. The effect of varying the position of greatest beam might be studied to this end.

The question of the disposal of fuel is rendered difficult because the present trend of land machine design, which is to put the petrol in the top plane and use gravity feed, is unfavoured towards stability on the water in the case of marine aircraft. Probably in the majority of cases the hull position will be used.

It is perhaps desirable to emphasise the need for water rudders on all marine aircraft. They are particularly useful when approaching a slipway or in crowded waters. The mounting of a water rudder should be such that there is little risk of its being damaged when the craft is handled on the slipway, a trouble which has often occurred in the past. In amphibians a combined steering tail skid and water rudder is sometimes fitted. It is perhaps better to approach the design of such a fitting with the idea of making a really efficient steering tail skid and then to add the necessary surface to make it effective as a water rudder.

A neglected point in past designs has been the lack of provision for bilgeing wing-tip and tail floats if such are fitted (*22h*). There are mechanical problems to be solved, but the lack is severely felt when the parts referred to become waterlogged, not necessarily owing to being holed, but because of repeated water shocks over a long period causing small leaks.

Another very important point is the desirability of having ailerons on the top plane only. This applies to all types with the questionable exception of the twin-float seaplane. It should be remembered that damage to a lower plane aileron or its attachments which has occurred previous to taking off may become apparent in flight by the locking of the control with possibly grave results.

A serious risk attendant upon the use of a bulkheadless hull, or one with longitudinal or keelson bulkheads only, is that of bilge water running from one end to the other as the incidence of the machine changes in flight, with dangerous effects on control. As even a half-bulkhead, say one foot deep, would interfere with hull flexibility, there is here a problem of which the satisfactory solution would be very valuable in view of the increasing popularity of the flexible hull. Apart from the type of hull construction it is perhaps desirable to provide watertight compartments in the extreme nose and tail of all kinds of craft as the various objections to the use of bulkheads generally apparently do not apply to these parts, which may provide a convenient reserve of buoyancy capable of maintaining something above water as the last resource of the crew after a crash.

Inferences and Speculations

There are certain conclusions to be drawn from the history of marine aircraft, as will be realised from the foregoing brief account of recent developments.

It would appear to be necessary to protect the propeller from green water, especially in smaller craft, by placing it immediately above a main float or boat. For this reason alone the twin-float single-engined seaplane is unsatisfactory as a type when seaworthiness is important. It must be remembered in this connection that it is not only the propeller itself that suffers from the blades hitting water. The shocks to the engine components and mounting are also severe (*3c*). Metal propellers may well be found to possess increased durability, but their comparative lack of elasticity may be found disadvantageous. Theoretical con-

siderations will show, in addition, the harmful results of the increased weight of metal propellers, particularly in regard to gyroscopic couple. This is not only an aerodynamic question, since the rapid angular variation of the propeller shaft axis during porpoising may cause high stresses.

Considering the two remaining single-engined types, the flying boat and the single-float seaplane, it appears that a desirable flying boat should carry its tail on one or more fuselages, the only economical structure to carry it sufficiently clear of the water (*3a*, *3c*, *22f*). In this case the separate nomenclature as to flying boat and seaplane really refers to the disposition of crew, which is generally settled from considerations other than that of seaworthiness. Whether the single-engined flying boat, with part at least of its crew in the hull, should be a single-fuselaged tractor or a necessarily twin-fuselaged or outrigger pusher, must be decided in favour of the pusher type when possible, as in this type the bows can conveniently have greater freeboard as the question of propeller clearance does not arise there, and freeboard aft is of less importance. But, nevertheless, questions of structure and disposition of crew may result in a single-fuselage tractor being decided upon.

It appears likely that some version of the Dornier-Manning partially submerged boat-built wing or an abnormally broad hull may eventually replace the conventional structure with its wing-tip floats. It should be clearly understood that it is not only that wing-tip floats are themselves undesirable as the advantages, in any case, of boat building the bottom plane that makes this development so important (*22c*, *22f*).

It is possible that the final solution of the lateral stability problem will be in the form of a hull of which the metacentric height is just positive, but with the addition of small emergency wing tip floats which will come into use occasionally, when turning in a strong wind, for instance. Normally both of these would be well clear of the water.

Much larger types of single-engined flying boats should become practicable with the engines now available, such as the Rolls-Royce Condor and the Napier Cub, and a single-engined pusher flying boat to carry the service load of an F.5 or P.5 might make a very attractive machine (*26a*).

An advantage possessed over twin-engined types generally which has not hitherto been mentioned is the smaller lateral moment of inertia of the latter, so that the craft heels more readily with the sea with a reduction in impact stresses.

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THE LAUNCHING OF AIRCRAFT FROM SHIPS

BY SQUADRON LEADER L. J. WACKETT, D.F.C., A.F.C., B.SC., ASSOCIATE FELLOW.

As it may be necessary in the future, as it has been in the past, to launch aircraft from ships, other than aircraft carriers with large aerodrome decks, the following investigation has been carried out.

It is required to find the minimum propeller thrust necessary to enable an aircraft (particularly a seaplane or flying boat) of known weight and fineness, to take off from a railway platform, on a ship steaming at given speed.

The following assumptions are made:—

(1) The air is supposed still relative to the earth. The wind velocity relative to the ship is then due entirely to the speed of the ship.

(2) The aircraft is assumed to move along the platform at a constant attitude. The attitude taken is that for the best climbing rate.

(3) The resistance of the aircraft is taken as equal to Av^2 where A is constant for the attitude at best climbing rate.

(4) It is assumed that the aircraft shall take off by running along a short railway track. This has been done because it is thought that some form of railway track would be preferable to a staging on small naval vessels, and also on the forecastle of mail steamers.

The arrangements of the trolley wheels may vary, but it has been assumed that the resistance due to friction on the railway is equal to Bv where B is a constant.

(5) The propeller thrust has been assumed constant for the whole length of the run. It is therefore necessary to suppose that the engine has been opened up to full power before allowing the aircraft to move along the railway. This assumption is permissible owing to the very small diminution in thrust up to the speed of taking off.

Let (v) ft./sec. = aircraft speed relative air.

Let (V) ft./sec. = speed of ship relative to the earth.

Let (T) lbs. = thrust of airscrew.

The railway friction is zero when $v = V$, that is when the aircraft is stationary relative to the ship.

The force tending to accelerate the aircraft is therefore: (Thrust)—(railway friction)—(air resistance on aircraft)

$$= T - B(v - V) - Av^2$$
$$= (T + BV) - Bv - Av^2$$

As V, the speed of the ship, will be constant during the time taken to take off, then $(T + BV)$ will be constant $= T_1$ say.

We have then

$$T_1 - Bv - Av^2 = (m/g)(dv/dt) = (m/g)(dv/dx)(dx/dt) = (m/g)(v)(dv/dx)$$

where x is the length of run relative to the earth and m is the weight of the aircraft.

Whence

$$dx = (m/g)\{ v/(T_1 - Bv - Av^2) \}\, dv$$

Integrating we get

$$x = -(m/g)\int [\{B/2A + 1/2A(-B - 2Av)\}/(T_1 - Bv - Av^2)]\,dv$$

$$= -(m/g)[(B/2A)\int dv/(T_1 - Bv - Av^2) + (1/2A)\int \{(-B - 2Av)/(T_1 - Bv - Av^2)\}\,dv]$$

$$= -(m/g)[(B/2A^2)\int \{dv/(-(T_1/A + Bv/A + v^2) + (1/2A)\log_e(T_1 - Bv - Av^2)\}]$$

which we shall call equation (1).

To integrate the term

$$\int dv/-(-T_1/A + Bv/A + v^2) = \int dv/-\{(B/2A + v)^2 - (B^2/4A^2 + T_1/A)\}$$

$$= \int dv/-\{(\alpha + v)^2 - \beta^2\}$$

where

$$\alpha = B/2A \text{ and } \beta = \sqrt{(B^2/4A^2 + T_1/A)}$$

and since $(\alpha + v)^2$ is less than β^2

$$= (1/2\beta)\log_e(\beta + \alpha + v)/(\beta - \alpha - v)$$

Substituting in (1) we get

$$x = -(mB/4gA^2\beta)\log_e(\beta + \alpha + v)/(\beta - \alpha - v) - (m/2gA)\log_e(T_1 - Bv - Av^2) + C$$

which we shall call equation (2), where C is a constant of integration.

When $x = 0$, that is, at the instant of starting, $v = V$, and substituting in (2) we get

$$C = (mB/4gA^2\beta)\log_e(\beta + \alpha + V)/(\beta - \alpha - V + (m/2gA)\log_e(T_1 - BV - AV^2)$$

which gives a value of C for the particular speed of ship during the take off.

By substituting the numerical values in (2), the length of run (x) relative to the earth, to attain the minimum flying speed v can be found.

It is now necessary to find the time required to attain minimum flying speed and this is done as follows:—

Taking the force equation as before,

$$T_1 - Bv - Av^2 = (m/g)(dv/dt)$$

whence

$$dt = (m/g)\,dv/(T_1 - Bv - Av^2)$$

Integrating,

$$t = (m/g)\int dv/(T_1 - Bv - Av^2)$$

by the same method as before

$$t = (m/2gA\beta)\log_e(\beta + \alpha + v)/(\beta - \alpha - v) + C_1 \quad . \quad . \quad (3)$$

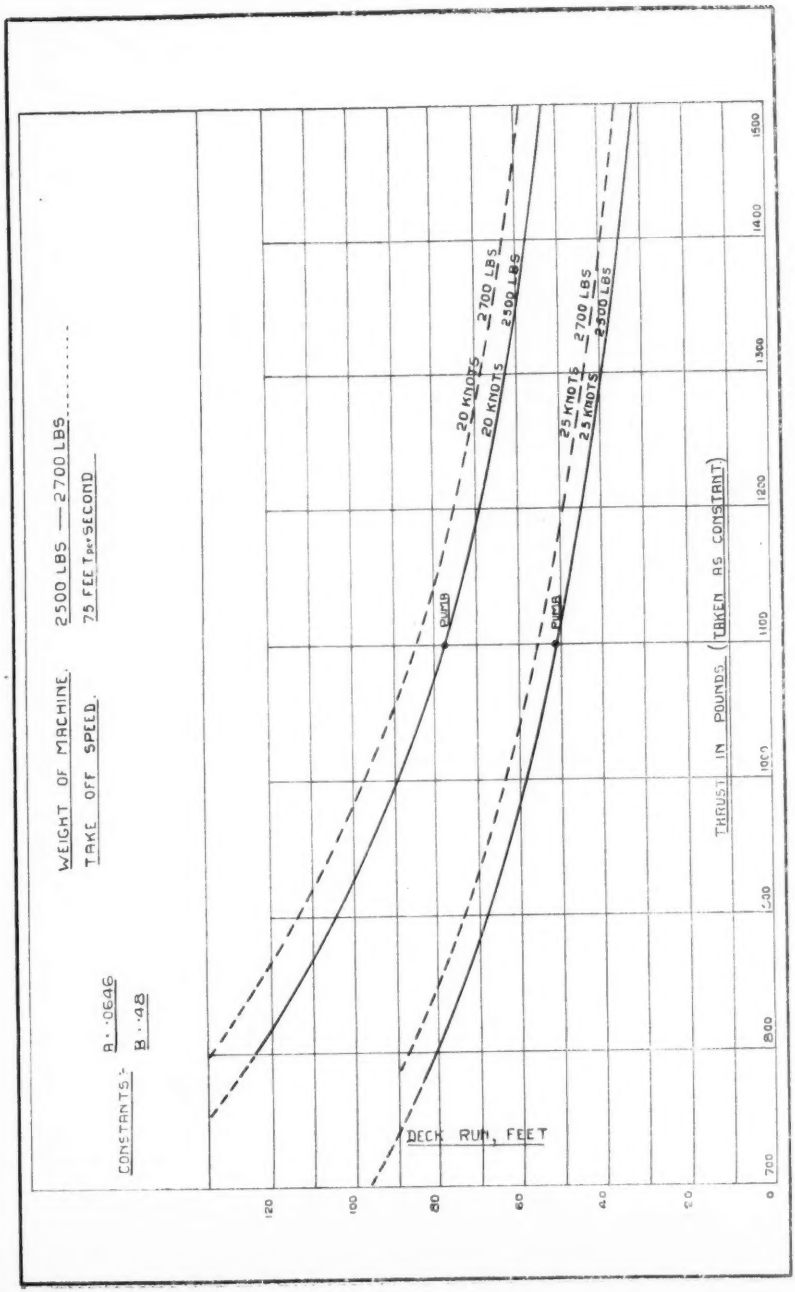
where α and β have the same values as previously and where C_1 is a constant of integration.

When $t = 0$, that is, at the instant of starting, $v = V$ and by substitution in (3), we get

$$C_1 = -(m/2gA\beta)\log_e(\beta + \alpha + V)/(\beta - \alpha - V)$$

which gives the value of C_1 for the particular speed of the ship during the take off.

While the aircraft is running on the railway the ship will be moving forward with speed V. The distance moved by the ship, relative to earth during the


WEIGHT OF MACHINE. 2500 LBS — 2700 LBS.
TAKE OFF SPEED. 25 FEET per SECOND
CONSTANTS:- A·-0646
B·-48
20 KNOTS 2700 LBS
20 KNOTS 2500 LBS
25 KNOTS 2700 LBS
25 KNOTS 2500 LBS
PUMB
PUMB
DECK RUN, FEET
THRUST IN POUNDS (TAKEN AS CONSTANT)
0
20
40
60
80
100
120
700
800
900
1000
1100
1200
1300
1400
1500

take off will be Vt and it is then obvious that the length of run along the railway will be $x - Vt$.

These calculations have been performed for a number of ship speeds and for aircraft of a number of different weights. Appropriate values of the constants A and B have been taken.

The minimum flying speed was taken as 75 ft. per sec. and was assumed constant for small variation in total weight of aircraft.

The curves emphasise the pronounced advantage of a speedy ship for such a scheme.

Between the limits investigated an increase of ship speed of one knot will permit the total weight to be increased by 200lbs. for the same length of run in taking off.

Using these curves in conjunction with curves of propeller thrust it is possible to ascertain readily the feasibility of using any particular engine in an aircraft intended for this purpose. For instance, having estimated that a Puma engine could be installed for a total weight all up of 2,500lbs. and that a suitable propeller is obtainable which would give a thrust of 1,100lbs. at a take off speed of 75 ft. per sec. it is then seen by reference to the curves that the deck run will be about 52 feet when the ship's speed is 25 knots, and about 77 feet when the ship's speed is 20 knots.

Yet another use of these equations is in the design of catapult launching gear from stationary or moving ships. It is possible to calculate directly the thrust of the catapult gear necessary to augment the engine thrust in order that the taking off speed may be attained in a run of given length.

THE EFFECT OF VARIABLE GEARING ON AEROPLANE PERFORMANCE

BY ANNIE D. BETTS, B.SC.

It has been shown that considerable improvement may be made in the performance of an aeroplane by the use of an airscrew, the pitch of which can be varied. The matter was discussed by Mr. H. A. Mettam in R. and M. 577, Part II.* There are, however, certain practical drawbacks to the use of a variable pitch airscrew. Such an airscrew is expensive to construct and probably more liable to breakage or derangement in flight than the ordinary type. It also imposes on the pilot the necessity of making constant and accurate use of the variable pitch control, if the full advantages of the system are to be obtained.

The present writer considered, therefore, that it might be worth while to inquire whether a similar improvement in performance could not be obtained by other and simpler means, namely, by the use of variable gearing between the engine and airscrew (the latter being of the usual fixed pitch type). The calculations have been made for the same machine as was used to illustrate R. and M. 577, the S.E.5 with Wolseley Viper engine. As in the variable pitch airscrew calculations, the weight has been increased from 1,976lbs. to 2,000lbs., thus allowing 24lbs. for the weight of the gearing.

The data are therefore:—

$W = 2{,}000$lbs.

$S = 248$ sq. ft.

For the airscrew we have:—

$D = 7.87$ft.

P the experimental mean pitch of no thrust $= 7.6$ft.

$\eta = 0.70$.

$K_t = 12.4$ and $K_q = 96.0$. (These quantities are such that $K_t k_T$ and $K_q k_Q$ both $= 1.0$ when $V/nP_m = 0.5$. See R. and M. 474, Appendix.) Curves for k_L and k_L/k_D, b.h.p. and r.p.m., engine b.h.p. factor $f(\sigma)$ and height, air density σ and height, and the airscrew characteristics K_t and K_Q and V/nP_m will be found in R. and M. 577, which should be consulted by those desiring to verify the results following.

Assuming that infinitely variable gearing is at our disposal, the performance can be calculated by a method similar to that used in R. and M. 577. Guess a number of values of R (the gear ratio), and thence calculate the forward speed and best rate of climb, on the assumption that the r.p.m., and consequently the horse-power, are kept constant at the values 1,900 and 212 respectively. (Compare R. and M. 577.) As there is certain to be a loss of power by friction, due to the gearing, it has been assumed that this loss amounts to 5 per cent. of the total, so that the effective power at 1,900 r.p.m. is 201.5.

The formula of R. and M. 474,

$$k_Q = 550 \text{ b.h.p. } f(\sigma)/2n\rho n^3 R^3 D^5$$

where $f(\sigma)$ = engine factor and ρ = air density, n = revs./sec. of the engine,

* Empirical Formulæ for a Variable Pitch Airscrew, with Applications to the Prediction of Aeroplane Performance. By Miss A. D. Betts, B.Sc., and H. A. Mettam. February, 1919.

R = gear ratio and D = airscrew diameter, is made use of to find the values of k_0 corresponding to given values of R. With our data this formula becomes:—

$$k_0 = (0.00775 \times f(\sigma)/R^3 \times \sigma)$$

where σ is relative air density.

Two examples only of the working are given here, for economy of space; the results for 6,500, 10,000 and 15,000ft. have also been worked out and are given in Table I.

2,000ft.

R	$K_q k_0$	V/nRP_m	V ft./sec.	k_D	k_L/k_D	η/η_{max}	η	$V=\eta(k_L/k_D)\times 53.0$	$v\ (k_L/k_D)$	v ft./sec.
.90	1.015	.476	103.2	332	9.03	.829	.58	277.6	174.4	19.3
.91	.982	.526	115.3	266	9.05	.885	.62	297.4	182.1	20.13
.915	.966	.561	123.7	231	8.84	.919	.643	301.5	177.8	20.12
.92	.950	.568	126.0	223	8.75	.925	.647	300.4	174.4	19.94
1.00	.740	.757	182.4	106	5.29	.997	.698	195.7	13.3	2.514
1.005	.730	.765	185.2	103	5.15	.993	.695	189.8	4.6	0.893
1.01	.718	.772	188.0	100	5.00	.990	.693	183.7	−4.3	−0.86

On plotting, we find that v (rate of climb in ft./sec.) is a maximum at $R=0.912$ and is then = 20.13; v is = 0, and the machine is therefore flying level, at $R=1.008$; V here is 186.5 ft./sec.

In this table, $K_q k_0$ is obtained from the formula for k_0; V/nRP_m is then read off from Fig. 1 of R. and M. 577; V is thence found by multiplication; $k_L=3400/V^2$, k_L/k_D and η/η_{max} are read off Figs. 10 and 1 of R. and M. 577 respectively, and v is obtained by means of the formula

$$v=(k_L \times HP \times f(\sigma)\ 550/k_D \times W) - V(k_L/k_D)$$

20,000ft.

R	$K_q k_0$	V/nRP_m	V ft./sec.	k_D	k_L/k_D	η/η_{max}	η	$V=\eta(k_L/k_D)\times 24.55$	$v\ (k_L/k_D)$	v ft./sec.
.87	.942	.577	121.0	.436						
.875	.925	.597	125.9	.403	8.86	.946	.663	144.0	18.1	2.042
.88	.910	.613	130.0	.378	8.94	.959	.671	147.3	17.3	1.935
.91	.823	.693	152.0	.276	9.07	.995	.696	155.1	3.1	0.342
.915	.809	.705	155.4	.265	9.05	.998	.698	155.2	−0.2	−0.022
.92	.796	.715	158.5	.254	9.00	.999	.699	154.4	−0.1	−0.455

This gives level speed = 155 ft. sec. at $R=0.914$ and $v=2.04$ ft./sec. at $R=0.875$.

Further calculations were made on the assumption that the blades of the airscrew could be rotated (as if it were a variable pitch airscrew) and fixed in new positions, so as to give two other airscrews of $P_m=6.0$ and 9.0ft. respectively. The results for these are also included in Table I.

TABLE I.

Height.	S.E.5. $W=1976$lbs. $P_m=7.6$.	V.P. Airscrew. $W=2000$lbs. $P_m=$Variable.	$P_m=6.0$.	Variable Gear. $W=2000$lbs. 7.6.	9.0ft.
Speed.	No friction.			5% loss by friction.	
2,000	—	—	125.4	127.1	126.1
6,500	—	—	—	125.3	—
10,000	125.5	125.5	120.7	123.0	122.8
15,000	116.0	120.5	115.6	118.3	—
20,000	84.5	110.0	102.2	105.7	117.8
Climb.					
2,000	1020	1338	1259	1208	1100
6,500	760	1012	—	897	—
10,000	560	765	702	663	588
15,000	280	478	432	396	—
20,000	0	186	132	122	72
Ceiling is at	20,000	23,500	22,400	22,300	21,300ft.
		Gear Ratios.			
Speed.					
2,000	1.0	1.0	1.183	1.008	0.893
6,500	1.0	1.0	—	0.994	—
10,000	1.0	1.0	1.15	0.982	0.871
15,000	1.0	1.0	1.122	0.959	—
20,000	1.0	1.0	1.061	0.914	0.818
Climb.					
2,000	1.0	1.0	1.048	0.912	0.822
6,500	1.0	1.0	—	0.904	—
10,000	1.0	1.0	1.028	0.896	0.810
15,000	1.0	1.0	1.014*	0.884	—
20,000	1.0	1.0	1.016*	0.875*	0.787*

In the cases marked * the rate of climb is limited by the occurrence of the stalling attitude at the value of R given.

Some points in these results call for remark. In the first place it will be noticed that the airscrew of $P_m=9.0$ft. gives speeds which fall off much less rapidly as the ceiling is approached than do those of the other examples. This indicates that it should be possible to build a machine which would fly at a constant speed at all heights, and keep the engine revs. simultaneously at their most economical value, by the use of a variable gear.

Further, we see that if too low a gear ratio is used (especially if the P_m of the airscrew be small), it is possible to stall the machine. This is not however likely to occur where it would be most dangerous, at low altitudes, for there the best rate of climb occurs at a value of R greater than the stalling value. This fact may, however, limit the usefulness of the device unless some means of guarding against the difficulty can be found. Accidents might also result from this cause were the gear to become deranged during flight; but this could be obviated by so constructing the gear that, in case of breakage, it took up automatically a reasonably high value of R.

An infinitely variable gear is open to one of the objections to a variable pitch airscrew; it requires constant attention from the pilot.

These considerations suggested that it might be possible to get better results from a three-speed gear, of the type familiar to motorists, in place of an infinitely

variable gear. Inspection of the figures for the case $P_m=7.6$ indicate that the ratios should be:—

$R=1.0$, for flying level up to at least 10,000ft.

$R=0.9$, for climbing from the ground to 15,000ft. and for flying level above that height.

$R=0.88$, for climbing at heights above 15,000ft.

The working (omitted) proceeds by guessing several values of n (and therefore of the b.h.p.), calculating k_0 and thence the other quantities as before. This process must be repeated for each altitude, and separate calculations are in general needed for speed and climb as their gear ratios are generally different. The results are:—

TABLE II.

Height.	3-speed gear (5% friction loss).		S.E.5 (no friction).	
Speed.	Speed.	Revs.	Speed.	Revs.
2,000	125.3	1900	—	—
10,000	122.0	1855	125.5	1900
20,000	117.8	1953	84.5	1590
Climb.	Climb.	Revs.	Climb.	Revs.
2,000	1163	1910	1020	1700
10,000	666	1910	560	1675
20,000	118	1890	0	1590

The three-speed gear machine is very near the stalling attitude at the value of climb for 20,000ft.; possibly this might be avoided without much loss of performance by slightly raising the lowest gear if it is thought desirable to do so. The climb and speed level are nearly the same as those for the infinitely variable gear machines with $P_m=9.0$ and 7.6ft. respectively.

It appears, therefore, to be possible to construct a combination of variable gear and airscrew which will allow of a machine being flown at a nearly constant speed at all heights, while the engine revs. are kept at (or close to) any chosen value. This, it will be noticed, could apparently be done with a two-speed gear, if economy and simplicity so dictate; though the climb of such a machine at great heights would be adversely affected by the absence of the third gear. Against this must however be set increased immunity from stalling due to a low gear ratio before referred to.

If an accurate infinitely variable gear with a gear ratio recorder or dial were available, it would probably be of much value as an instrument of full-scale research, apart from any possible commercial or military advantages it might have. It is hoped, therefore, that this paper may draw the attention of aero engine designers to the matter even if considerations of engine construction and of the severe stresses involved render the practical value of such a gear doubtful.

CORRESPONDENCE

October 12th, 1923.

To the Editor of the JOURNAL OF THE ROYAL AËRONAUTICAL SOCIETY.

ON THE STABILITY OF AERO ENGINES

SIR,—In response to a much-esteemed invitation from the Secretary of the Society, I beg to submit the following comments upon the paper contributed by Captain J. Morris to your April issue under the above title, and upon the subject generally.

In these comments I am enabled by kind permission of the Director of Research, Air Ministry, to make certain references to work which has been done in regard to torsional vibration at the Air Ministry, and to that now proceeding at the Royal Aircraft Establishment.

Resonant torsional vibration is a matter in which I am deeply interested, having found that serious troubles with certain important aircraft engines have been attributable to it in greater or less degree, and to my mind there is no question that further investigation of the problems involved will be much more than repaid by the resulting advance in engine design.

A purely mathematical treatment such as that given in the paper proves upon application to be inadequate, and may indeed be quite misleading, since, if the equations are used with blind faith, the results obtained will most probably be very wide of the mark; a word of warning is thus necessary.

It is not that the mathematical reasoning is unsound, but that it is necessary to exercise much care and judgment in determining the values to insert in the formula, and these are obtained most satisfactorily by experiment. For example, in the case of an eight-cylinder 90 deg. Vee geared engine which was investigated during 1918 because bad torsional failures were occurring, a purely mathematical treatment, based on the computed stiffness of the crankshaft journals and of the airscrew shaft, indicated that in the region of normal running speed, viz., 2,000 r.p.m., the *secondary* impulses of the engine torque synchronised with the lowest natural frequency of the crankshaft airscrew system, whereas a revised calculation based on the results of static twisting tests showed that the troubles experienced might be attributed to the *main* engine impulses producing torsional resonance.

In these investigations, which were made at the Air Ministry under my immediate direction, I treated the crank-throws as virtual flywheels and derived equations by the methods outlined by Chree, Millington and Sankey,* but developed to take into account the effects of the gearing. Captain Morris arrives at the same equations in a somewhat different way; also, he evolves some more general ones which take into account the *bending* of the crankwebs in the plane of their rotation, but he makes no reference to their *twisting*. For a crankshaft of normal design, the bending effects must be small, whereas the twisting effects may be quite large.

In the case mentioned above, static twisting tests were made on the crankshaft and on the airscrew shaft, because I doubted the validity of the stiffness computations. The tests revealed that the twisting of the crankwebs and crank-

* Proceedings Inst. of Mech. Engineers, 1904.

case considerably reduced the crankshaft stiffness, and that the effective length of the airscrew shaft varied with the torque, owing to the changing grip of the hub upon the shaft taper.

Although these investigations indicated that the troubles could be attributed to resonance effects, there was no direct means of settling, beyond dispute, the extent to which such effects were responsible for the failures. Even with the static tests made, one felt that the method of tackling the problem required some direct experimental support before much reliance could be placed on the results. Suitable experiments could not be undertaken at the time, and the results of the investigations made were considered with due reserve in deciding upon such alterations to the engine in question as could be entertained.

One such alteration was in respect of the reduction gearing, which was of the plain spur type with stub teeth. The pinion on the crankshaft had 27 teeth and the wheel on the airscrew shaft 45 teeth, so that the reduction ratio was 3 : 5. The torque reaction on the nosepiece containing the gears was thus two and two-third times the torque at the crankshaft pinion, and this might have accounted for the failures apart from resonance, particularly as the nosepiece was unsupported by the engine bearers.

If the torque variation alone was responsible, decreasing the gear ratio would reduce the torque reaction on the nosepiece, but the investigations indicated that this change would bring down the synchronous speed nearer to the running speed. On the other hand, increasing the gear ratio would make the synchronous speed more remote, but, disregarding resonance effects, would increase the torque reactions on the nosepiece. As radical alterations in design could not be effected, some gears giving a ratio of 35 : 37 were made with the object of reducing the torque reactions on the nosepiece and the torque in the airscrew shaft at the expense of airscrew efficiency. At the same time, owing to my apprehensions from the torsional vibration standpoint, some gears of 25 : 47 ratio were made for trial.

The first two engines fitted with 35 : 37 ratio gears suffered crankshaft failure under test on the hangar after about thirteen hours' running in each case, and this ratio of gearing was abandoned. It is very significant that the decreased ratio of gearing increased the troubles, for crankshafts had not broken with the original gears.

Owing to the intervention of the Armistice, the behaviour of engines fitted with the 25 : 47 ratio gears was not fully ascertained, but, from short bench runs and a few flights made, an improvement appears to have been effected.

Considering the matter now in the light of subsequent experience with other types of engine, I have little doubt that torsional resonance was chiefly responsible for the very serious failures that occurred. The investigations, so far as they went at the time, were communicated to the firms concerned, but have not been published. It was not, and still is not, easy to arrive at definite conclusions in such a case, for much remains to be discovered about the stress and strain changes a shaft will withstand for prolonged periods of running, making due allowance for oil holes, threads, splines, keyways, and fillets; and in this connection the paper read by Professor Jenkin before the Society during the last session is of extreme interest.

One has to remember that the necessary strength and stiffness must be obtained without undue weight, and it is only by scientific design that a high performance aircraft engine can be produced without a very real danger of torsional resonance trouble; this is particularly so in the case of radial engines.

Torsional resonance always exists in some degree, and the particularly pernicious thing about it is that the fact of its being present to a dangerous extent often does not manifest itself unmistakably until after prolonged periods of

running. Experience has shown that a test of 50 hours' duration is insufficient, and that at least 100 hours' successful running (at nine-tenths full power) is required to demonstrate the non-existence of the weakness in question—that is, in the absence of a satisfactory instrument devised and used for actually measuring the degree of resonant vibration that exists. The evolution of such an instrument will be referred to later in connection with the work proceeding at the Royal Aircraft Establishment.

The three main portions of Captain Morris' paper may be considered as :—

1. Investigation of Whirling.
2. Investigation of Airscrew Vibration.
3. Investigation of Torsional Resonance;

and some comments will now be made on each of these portions in turn.

Firstly, as regards Whirling

It is common engineering experience that shafts may be put through their whirling speeds and that they come back to a safe condition of running at higher speeds. The usual explanation is that the centre of gravity of the mass is not on the shaft axis and that beyond the critical speed the shaft deflects in such a way as to bring the centre of gravity nearer and nearer to the actual axis of rotation as the speed is increased. At first sight such a condition is unstable, but this impression is gathered by considering the shaft to deflect in one plane and to remain so during speed changes. My conception of the matter is that, as the shaft is accelerated through the whirling speed, the accelerating torque applied, combined with the tendency of the moment of momentum of the mass to remain constant, causes the shaft to take some slightly helical form, thereby complicating the motion in such a manner that stability results above whirling speed. There is a little experiment which might be made to test the soundness of this conception respecting whirling. Imagine a disc rotating about the normal through its centre, placed vertically to eliminate the effects of gravity, and attached to the disc through the medium of two equally-loaded springs placed radially, a mass whose position of rest is at the disc centre. If the mass is constrained to move in a diametrical direction, its angular velocity must be always that of the disc as it is varied, and when the speed corresponding to the "critical speed" of the arrangement is exceeded, the mass may be expected to fly out to a stop on one side or the other of the centre. If, however, the constraints be removed, one may expect the mass not to remain on a particular diameter, and, in accordance with the behaviour of shafts such as that of the De Laval turbine, it should assume a stable position nearer and nearer the disc centre. Perhaps some reader interested in the mathematics of whirling will try this arrangement. By putting the axis of rotation horizontal, the effects of gravity would be introduced and could be studied by means of a suitable stroboscope. In actual practice the mass on the shaft may have an appreciable polar moment of inertia, in which case stability may be influenced by gyroscopic forces.

I am not satisfied that Captain Morris's treatment proves the existence of the "speed of resonance," for it is clear that an investigation is at fault which does not lead to results consistent with actual observations.

Secondly, as regards Airscrew Vibration

This is perhaps the most original part of Captain Morris's paper, but one feels that the time is not yet for complicating the investigation of torsional vibration by considering airscrew-blade vibration in conjunction with it, although further work may show that this cannot be avoided. A given design of engine is fitted with various designs of airscrew according to the aircraft in which it is installed, and it is expedient to take as a basis its behaviour when fitted with an

airscrew which may be taken as rigid so far as vibration of the blades in the plane of rotation is concerned, and to treat the behaviour with any actual airscrews as particular problems in which the basis behaviour is modified. It may be mentioned that the polar moment of inertia of an airscrew is so large in comparison with the airscrew shaft and crankshaft masses that differences in magnitude of this quantity have little effect on the synchronous speed.

One despairs of reaching solutions of airscrew blade vibration mathematically, as the deflections are those of a twisted strip of varying sectional form; moreover, the frequencies are functions of the speed of revolution, whereas those of the virtual flywheel system are independent of this. Thus the investigations made by Captain Morris may serve as a guide, but prove to be based on assumptions that are too crude to enable the results to be used in computations. In the case of some tests made on a radial engine fitted with an airscrew and subjected to an alternating torque with the crankshaft not rotating, it was observed that at a certain frequency of torque variation, lateral vibration of the airscrew blade occurred with an amplitude of about $\pm \frac{1}{2}$in. at the blade tips. At the same time the amplitude of torsional vibration was considerably diminished, so that the lateral vibration appears to have had a damping effect on the torsional vibration.

With the shaft rotating the natural frequency of the lateral blade vibration would be increased by centrifugal force and the behaviour of the system modified accordingly. It should be mentioned that the phenomenon was associated with the engine mounting, as it was not observed when the tests were repeated with the engine mounted differently.

The error of assuming the airscrew to be rigid in the plane of rotation has been estimated by Dr. A. A. Griffith at less than $\frac{1}{2}$ per cent. of the synchronous speed, and an assumption which makes a result not more than $\frac{1}{2}$ per cent. low is quite satisfactory for practical purposes since other errors in the investigation may give an aggregate error of ± 3 per cent.

The reader will find some interesting remarks on the subject of airscrew blade vibration, by Griffiths and Hague, in R. & M. No. 452, June, 1918 (Advisory Committee for Aeronautics).

Thirdly, as regards Torsional Resonance

In his consideration of the two flywheel arrangement shown in Fig. 1, page 184, Captain Morris confuses matters by taking a system which is incomplete, and his mathematics only hold good if the gear P_2 is actuated by an inertialess system. The confusion is removed if instead of P_2 being taken as a gear, it is assumed to be the crank of a radial engine, the torque of which is produced by (inertialess) gas forces operating on the pistons, the inertia effects of the pistons themselves being that of one half their total mass located at the crank pin centre and included thus in the flywheel effect of the big end, crank pin, crank webs and balance masses.

A system such as this is shown in Fig. 9, but the complication is there introduced of assuming the cranks to be appreciably flexible in the plane of their rotation, and, as previously mentioned, this is quite an unnecessary elaboration.

Captain Morris states that within his knowledge the treatment he has adopted is entirely original, from which it is clear that he is very slightly acquainted with the work of others in this field.

A general treatment of a number of masses or flywheels on a shaft, subjected to a series of forces or torques, is given in the Appendix of Perry's "Applied Mechanics," the equations of motion being set down in the same fashion as in the paper under review. Moreover, in dealing with forced vibrations it is quite usual to express the varying load as a Fourier series, and the reader is referred

to "Vibrations of systems having one degree of freedom" * by the late Professor Hopkinson for a very clear outline of the method, in which, incidentally, the effects of damping are taken into account. Captain Morris makes no mention of damping, although this, *inter alia*, determines how near to the synchronous speed it is safe to run an engine. On this point it may be remarked that, assuming no damping, which is the safest thing to do for design purposes, there is a definite increase in torque variation produced by resonance at every speed up to the lowest synchronous speed and between synchronous speeds, and, since fatigue failure is largely a question of range of stress variation, it is clear that the amplitude of this variation at running speeds requires to be within certain limits. This amplitude can be calculated from the value of the synchronous speed, if known; and, by way of example, it has been found that the resonant effects at 1,600 r.p.m. may be sufficient to cause failure in a shaft system having a synchronous speed so far removed as 2,100 r.p.m., although, apart from resonant effects, the shaft would have a sufficient margin of strength.

Captain Morris's investigations are very much complicated by the inclusion of possible forms of airscrew blade vibration in relation to each type of engine, whereas according to Dr. Griffith's investigation, the assumption of airscrew rigidity in the plane of rotation is normally justified and the complication of taking it into account is unnecessary from the practical standpoint. For my own part, I prefer to assume the airscrew to be rigid and to build up the equations for the more elaborate flywheel systems from those for the simpler ones, as in this way one gets a better conception of the ways in which vibration may occur, the roots of the equation conveying clear physical meanings. This method also has the great advantage that it does not involve the use of really difficult mathematics.

Although the foregoing remarks are definitely critical, it is fully appreciated that a good deal of work and much mathematical ingenuity has been put into the investigations Captain Morris has made, and his approximate formulæ given on pages 210 and 211 are mathematically interesting.

As regards the effect of gearing, the method used in connection with the eight-cylinder engine previously mentioned was substantially that which Captain Morris gives.

In conclusion, brief reference will be made to some investigations of torsional resonance made, and in hand at the Air Ministry and the Royal Aircraft Establishment.

When renewing investigations subsequent to the Armistice, the synchronous speeds for certain single-throw radial engines were computed mathematically, and it was found that, in each case, the speeds were of the same order of magnitude as the running speeds, but that, according to the assumptions made in the calculations, they might be sufficiently far removed not to be of much importance; or, on the other hand, they might be dangerously close. The chief uncertainties were the true effective stiffness of the crankshaft, the permissibility of assuming the airscrew to be rigid in the plane of rotation, and the extent to which damping operated.

It was decided that the airscrew stiffness must be regarded as a matter for separate investigation in individual cases, and that in general the assumption of rigidity was justified for preliminary work; also that attention should be confined at first to single-throw radial engines, as this type is much simpler to deal with than multi-crank engines. Tests were made in the case of one such engine, comprising the static twisting of the shaft, and also the determination of the natural frequency of vibration by applying to the crank pin a tangential load about equal to the maximum crank effort of the engine, with the hub rigidly held, and suddenly

* Cambridge Engineering Tracts, No. 1, 1910.

removing the load, the resulting natural vibration being recorded photographically on a uniformly rotating drum.

Attached to the crank pin was a mass equivalent in inertia effects to the big end mass and the reciprocating masses. Close agreement was found between the frequency calculated from the stiffness tests and that recorded.

The design of engine in question had developed symptoms of torsional resonance trouble, and when the shaft was re-designed in the light of these investigations, the troubles disappeared, although but little increase in weight had been entailed by the alterations.

From the information gained in the course of these tests it does now appear to be possible to deal satisfactorily with the matter for new engines of the single-throw radial type when in the design stage. Even for engines of this type, however, it is desirable to get definite measurements of the amplitude of torsional vibration under various conditions of power and speed.

One point upon which more light is required is the degree of damping that occurs, and associated therewith the danger-speed range for the forced vibrations.

In the absence of heavy damping, the amplitude of vibration at speeds removed from the synchronous speed can be computed with a fair degree of accuracy, and provided one knows what the material will stand indefinitely in the matter of fluctuating stress, the danger range can be estimated.

Some progress has been made at the Royal Aircraft Establishment in the direction of actual measurement of cyclical twist changes. Promising polar diagrams of varying twist have been obtained photographically from the crank-shaft of a nine-cylinder radial engine when running at speeds approaching 1,500 r.p.m. during rough preliminary tests of an instrument which is being developed there. In these tests, resonance was observed of a magnitude which checks roughly with that previously computed for little damping, and one is encouraged to expect that with further improvement of the instrument, satisfactory quantitative results will be obtained at speeds up to 2,000 r.p.m. or higher.

By means of such an instrument it is hoped to make experiments which will put the investigation of the whole subject on to a more substantial basis than it has been hitherto.—Yours faithfully,

B. C. CARTER.